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Abstract

In this article, the existence of disproportionate environmental risk in low-income and/or minority communities is evaluated for the Phoenix metropolitan area. The results of the econometric estimation illustrate that advocacy against disproportionate risk can lead to paradoxical results, making minority and low-income individuals worse off. Specifically, it is concluded that in the process of siting potentially polluting activities, emphasis should not be focused on avoiding disproportionate risk per se, but rather on ensuring that affected populations share fully in making decisions that affect their environment. This result supports the more general proposition that pursuing environmental justice goals that are not directly tied to the individual welfare of communities at risk can result in the violation of the Pareto principle.

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I. Introduction

While there is no universally accepted definition of environmental justice (EJ), there is general unanimity that the central concern revolves around the idea that minority and low-income individuals, communities, and populations should not be disproportionately exposed to environmental hazards. That is, low-income and minority communities should not be exposed to greater environmental risks than other communities through the siting of locally undesirable land uses (LULU's), the enactment of environmental and land use regulations, the enforcement of those regulations, and the remediation of polluted sites (Been and Gupta, 1997)[1].

A wide variety of empirical studies have concluded that disparate-impact discrimination does in fact exist since minority and low-income communities are at disproportionate risk for environmental harm.[2] Distributive equity concerns have quite naturally arisen over the documentation of disproportionate exposure of minority and low-income communities to land, air and water contamination. In response to these concerns, the environmental justice movement has become an attempt to equalize the burdens of pollution, noxious development, and resource depletion (Shrader- Frechette,

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[1] In 1997, the U.S. Environmental Protection Agency established the following definition of environmental justice, a definition that continues to guide U.S. federal environmental policy (U.S. EPA, 2003):

> "Environmental Justice is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies. Fair treatment means that no group of people, including a racial, ethnic, or a socioeconomic group, should bear a disproportionate share of the negative environmental consequences resulting from industrial, municipal, and commercial operations or the execution of federal, state, local, and tribal programs and policies."

[2] For example, Mohai and Bryant (1992) reviewed 15 studies conducted between 1971 and 1992 that attempted to provide systematic information about the distribution of such environmental hazards as air and noise pollution, solid and hazardous waste disposal, pesticide poisoning and toxic fish consumption. The results of these investigations were strikingly consistent. Regardless of the environmental hazard, and regardless of the scope of the study, in nearly every case the distribution of pollution was found to be inequitable by income and race. A 1992 study by the Environmental Protection Agency (EPA) concurred, providing evidence that minorities (e.g. African Americans, Appalachians, Pacific Islanders, Hispanics and Native Americans) who are disadvantaged in terms of education, income, and occupation bear a disproportionate share of environmental risk and death. More recently, Hird and Reese (1998) examined 29 indicators of environmental quality throughout the nation and concluded that pollutants tend to be distributed in a way that disproportionately affects people of color, even across different model specifications, different pollutants and when many other confounding characteristics are taken into account. Finally, a 2004 study conducted by the Natural Resources Defense Council concluded that a large percentage of U.S. Latinos live and work in urban and agricultural areas where they face heightened danger of exposure to air pollution, unsafe drinking water, pesticides, and lead and mercury contamination.

2002). More generally, the EJ movement has largely organized around the effort to redress the harms arising from disproportionate exposure to environmental risks.

Somewhat surprisingly, efforts to formally address perceived EJ violations have been largely frustrated.[3] The source of this frustration can be partly explained by legal requirements for establishing an EJ claim based on disparate-impact discrimination, and partly on procedural considerations under the EPA's administrative complaint process. Legal and institutional factors impacting the establishment of EJ claims are briefly discussed in the following section.

The principle obstacle to establishing a cogent EJ claim, however, concerns methodological debates over appropriate procedures for documenting disproportionate risk and the correct interpretation of study results.[4] Methodological considerations are addressed in section three as background for an empirical evaluation presented in section four of the existence of disproportionate environmental risk in low-income and/or minority communities in the Phoenix metropolitan area. The results of the econometric estimation illustrate that advocacy against disproportionate risk can lead to paradoxical results, making minority and low-income individuals worse off. Specifically, it is concluded that in the process of siting potentially polluting activities, emphasis should not be focused on avoiding disproportionate risk per se, but rather on ensuring that affected populations share fully in making decisions that affect their environment. Finally in the concluding section, it is argued that the results presented here illustrate a more generic problem for the EJ movement. Namely, pursuing EJ goals not directly tied to the individual welfare of targeted communities can result in the violation of the Pareto Principle.[5]

II. Legal Foundations for EJ Claims

The constitutional basis for EJ challenges to governmental discrimination lies in the equal protection clause. The Fourteenth Amendment expressly provides that the states

[3] In fact, it was not until 1997 that plaintiffs began winning cases on environmental justice grounds, mostly through emerging doctrines that did not require proof of intent (Gerrard, 1999).

[4] For a discussion of methodological issues, see Burns (2005) and Rachtshaffen and Gauna (2002).

[5] For a more general discussion of this possibility, see Kaplow and Shavell (2001, 2002).

may not "deny to any person within [their] jurisdiction the equal protection of the laws".[6] Implementation of EJ claims on constitutional grounds is circumscribed by a series of Supreme Court decisions requiring that 1) a governmental action must be involved for the equal protection clause to be violated, 2) private discrimination does not constitute a denial of equal protection, 3) the clause applies to local, state and federal levels of government, 4) only insidious or unjustifiable discrimination is prohibited, and 5) denial of equal protection requires proof of intent to discriminate (Weinberg, 1999).

Pursuit of EJ claims based on an appeal to equal protection have been frustrated by the proof of intent requirement. In principle, intent can be established by showing that a law was enacted with a discriminating purpose or that a neutral statute has been applied in a discriminatory manner. Alternatively, circumstantial proof of intent can be provided by documenting a greatly disparate impact on minority communities, implied by deviations from normal governmental procedures, or documented by statements evincing an intent to discriminate.[7] The most common procedural vehicle for the assertion of equal protection claims is a suit under 42 U.S.C § 1983. In practice, the burden of establishing discriminatory intent, as opposed to discriminatory impact, has proven to be so onerous that only the most egregious EJ cases have been successful using this line of argument.[8] As a result, EJ complaints have increasingly turned to Title VI of the Civil Rights Act and to the EPA's administrative complaint process to contest discriminatory permitting.

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[6] U.S. Constitution, amendment XIV, § 1.

[7] For discussion of intent issues and illustrative cases, see Weinberg (1999; pp5-20).

[8] Discriminatory intent continues to play an important role in EJ cases despite the inherent evidentiary burdens. For example, the Rhode Island Superior Court found that the state Department of Environmental Management failed to make EJ reviews as required by state law in siting a public school, but found no racial discrimination motivating the siting process (see Hartford Park Tenants Association v. Rhode Island Department of Environmental Management, CA. No. 99-3748, 2005 R.I. super. LEXIS 148 (Sup.Ct. R.I., Providence Oct. 3, 2005). Similarly, a community group in a predominately white area of Dallas argued that the decision by the Dallas Housing Authority to put public housing in their neighborhood was racially-motivated and violated their equal protection rights under the Fourteenth Amendment. The federal district court, however, held that the selection was not based on racial criteria (see Walker v. City of Mesquite, 402 F. 3d 532 (5th Cir. 2005). In another Dallas case, a federal court held that there was no intentional discrimination by the City of Dallas in allowing illegal dumping at a landfill in an African-American community since there was no evidence that the city acted differently toward this community than towards others (see Cox v. City of Dallas, 2004 U.S. Dist. LEXIS 18968 (N.D. Tex. Sept. 22, 2004)). For an overview of relevant EJ cases generally, see the American Bar Associations update service on the law of EJ at http://www.abanet.org/environ/committees/envtab/ejweb.html. Last accessed 7/2006.

A. Title VI of the Civil Rights Act (1964)

Title VI, which forbids discrimination by programs receiving federal financial assistance, offers the best opportunity for private citizens to bring EJ challenges against state or local agencies (Mank, 1999).[9] Because virtually every state environmental agency receives some funding from the EPA, almost all state permit decisions are potentially subject to Title VI's jurisdiction.[10]

Section 601 of Title VI expressly states that "No person in the United States shall, on the grounds of race, color, or national origin, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving federal financial assistance."[11] However, like the EJ challenges based on the Equal Protection Clause, Section 601 has been ineffective in preventing environmental inequities because the Supreme Court has held that proof of discriminatory intent is required (Mank, 1999).

Under Section 602 of Title VI, federal agencies are required to promulgate regulations that specify when the agency is engaging in racially discriminatory practices. The intent of the statute is that recipients of federal funds not engage in activities that have the effect of promoting disparate-impact discrimination. The emphasis on discriminatory impact or effect as opposed to discriminatory intent, has led to increased attention to the empirical documentation of disparate-impact discrimination in court proceedings.[12]

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[9] Civil Rights Act of 1964, Pub.L.No.88-352§§78 Stat.24P, 252-253, 42U.S.C. § 2000d. For discussions of the basic structure of Title VI as a vehicle for pursuing EJ claims, see Cole (1994), Colopy (1994), and Hammer (1996).

[10] In 1986, the federal government provided 46 percent of the funding for state air pollution programs, 33 percent of the funding for state water pollution programs, and 40 percent of the funding for state hazardous waste programs (see Lazarus (1987) for a discussion). By 1996, the EPA provided several billon dollars of federal funding under 44 different programs to about 1,500 recipients, including virtually all state or regional siting or permitting agencies (see U.S. Commission on Civil Rights, Federal Title VI Enforcement to Ensure Nondiscrimination in Federally Assisted Programs (June, 1996) for a discussion).

[11] 42 U.S.C. § 200d.

[12] A related and contentious issue is whether private rights of action exist under EPA's Title VI regulations. For quite some time, it was unclear whether agency regulations based on Section 602 of Title VI created private rights of action allowing plaintiffs to file suit in federal courts (Mank, 1999). Recently, however, the Supreme Court has ruled in Alexander v. Sandoval (2001) that private individuals can sue in cases where there is intentional discrimination, but that there is no private right to file a lawsuit concerning disparate-impact regulations. That is, the ability of individuals to enforce federal laws only exists when Congress provides for those rights. Private parties cannot enforce the duty of an environmental agency to engage in disparate-impact analysis (Lieberman, 2005). In a recent case this principle was reaffirmed by

The importance of convincingly documenting disparate impacts has been highlighted in recent litigation. For example, in 2005, the Sierra Club challenged a license issued by the Federal Energy Regulatory Commission (FERC) allowing construction of an 800-kilowatt power plant in Alaska. In reviewing and rejecting the challenge, FERC found that the Environmental Impact Study (EIS) showed no significant impacts to subsistence use of Glacier Bay National Park by Native Alaskan groups.[13] In contrast, plaintiffs prevailed in a case involving the City of Jacksonville when it was clearly established that predominantly minority neighborhoods were disproportionately exposed to toxic incinerator ash.[14] These and similarly situated cases illustrate that prevailing in EJ challenges has increasingly come to depend on empirically establishing disparate-impact discrimination, not on establishing discriminatory intent.

B. The EPA Administrative Complaint Process

The Supreme Court has stated that Title VI authorizes agencies to adopt implementing regulations that prohibit discriminatory effects, effects that have an unjustified adverse disparate impact.[15] Under EPA's Title VI implementing regulations[16], agencies receiving EPA financial assistance are prohibited from using criteria or methods of administering its program which have the effect of subjecting individuals to discrimination because of their race, color or national origin.[17] In 1998, the EPA issued the "Draft Revised Guidance for Investigating Title VI Administrative Complaints Challenging Permits" (DRG) to provide a framework for EPA's Office of Civil Rights (OCR) to process complaints filed under Title VI implementing regulations alleging discriminatory effects (EPA, 1998). This guidance provides a detailed framework for the

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the Court of Appeals for the D.C. Circuit, rejecting the argument that EJ claims can be based on Executive Order 12,898 or a Department of Transportation Order since neither of which allowed a private right of action (Communities Against Runway Expansion, Inc. v. Federal Aviation Administration, No.02-1267, 2004 U.S. App. LEXIS 1403 (D.C. Cir. Jan. 30, 2004)).

[13] More generally, FERC found it doubtful that there would be any material impact on the Native Alaskan groups (In the matter of Gustavus Electric Co., Proj.No.11659-003 (DERC Order Denying Rehearing March 24, 2005)).

[14] The incinerator ash exposed 4,500 residents, mostly African-Americans, to lead, arsenic, dioxins and PCBs. The City of Jacksonville agreed to pay $25 million to settle claims and to relocate some residents in neighborhoods near one contaminated site (Daily Envt. Rep. (BNA), p.A-2 (Sept. 6, 2005)).

[15] See Alexander v. Choate, 469 U.S. 287, 292-94 (1985); Guardians Ass'n v. Civil Service Comm'n, 463 U.S. 582, 589 (1983).

[16] 40 CFR part 7

[17] 40 CFR 7.35 (6)

OCR to process and investigate allegations about discriminatory effects resulting from environmental permitting decisions. Future internal EPA guidance documents will be issued to address enforcement related matters and public participation.[18]

The Title VI complaint process is illustrated in Figure 1. As shown in the flow chart, a complaint can be resolved in a variety of ways based on jurisdictional considerations, voluntary compliance, informal resolution, dismissal or rejection of the complaint, or funding termination for the recipient agency. As of November, 2003, however, only 17 of the 143 administrative complaints received over the previous 10 years satisfied the criteria to launch a preliminary investigation and only one went on to be adjudicated by the EPA (Faerstein, 2004).[19] In fact, approximately 3 out of 4 complaints that have been closed have either been rejected for investigation or dismissed after acceptance. Reasons for rejection range from no recipient of EPA financial assistance being involved, to insufficient allegations to constitute a cogent complaint, to the complaint being filed after the expiration of the 180 day deadline. Reasons for dismissal range from the complaint being withdrawn by the complainant, to the permit application being withdrawn or denied, to no adverse impact being found. To date, the OCR has denied claims of discrimination in all complaints that have been decided (Gerrard, 2003).

Of the closed complaints that were initially accepted for investigation but subsequently dismissed, approximately 40% fail to establish that an adverse impact exists. The evidentiary burden placed on complainants in this regard is significant and clearly enumerated. The framework used by OCR for documenting an adverse disparate impact involves six steps: 1) documenting that the contested permit meets the jurisdictional criteria provided in EPA's Title VI regulations,[20] 2) defining the scope of the investigation, including the nature and sources of stressors as well as impacts cognizable under the recipient's authority, 3) conducting impact assessment, 4)

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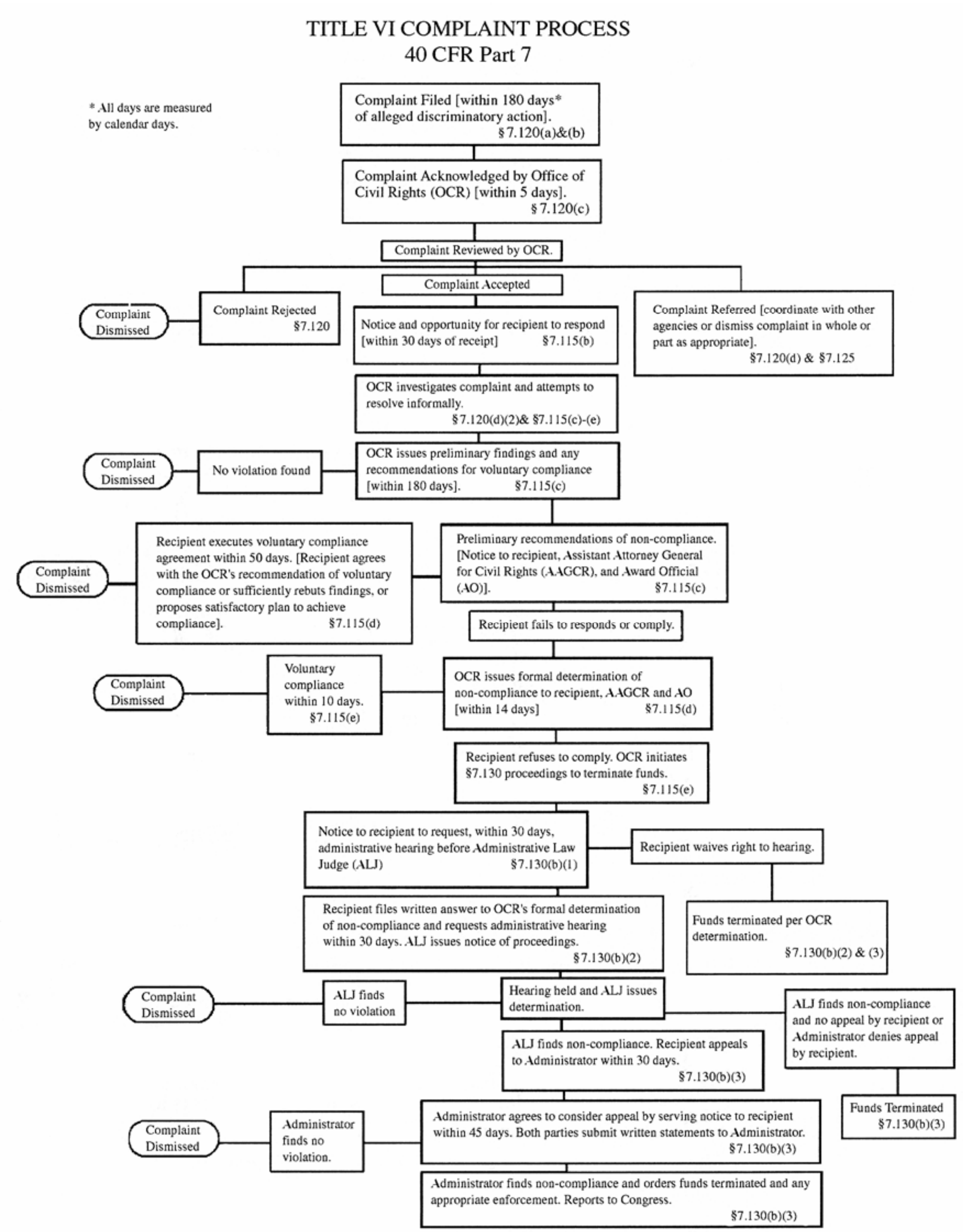
[18] The discussion in this section draws heavily from Revesz (2004) where a detailed discussion of the DRG is presented.

[19] The single case that was adjudicated involved the Select Steel facility in Flint, Michigan. The complaint was dismissed by the EPA stating that the recipient was in compliance with Title VI and even exceeded the requirements for public notice and participation. See Letter for Ann E. Goode, Director, EPA's Office of Civil Rights, Re: EPA File No. 5R-98-R5 (October 30, 1998).

[20] 40 CFR 7.120. See also section III.A.

Figure 1. TITLE VI COMPLAINT PROCESS



Source: Revesz (2004), Appendix B: Title VI Complaint Process Flowchart, II-64.

determining whether the risk or measure of impact is, in fact, adverse, 5) determining the characteristics of the affected population in terms of race, color or national origin, and 6) evaluating whether the disparity is significant. For EJ complainants seeking a remedy[21] under the EPA's administrative complaint process, failure to exhaustively document the existence of adverse disparate impact as outlined by the EPA's OCR virtually guarantees the complaint's dismissal.

Finally, it should be noted that documenting adverse disparate impacts associated with the issuance of an environmental permit is not sufficient to prevail with an EJ complaint under the EPA's administrative complaint process. It must also be shown that the impacts are "unjustified". The recipient has the opportunity to justify the decision to issue the permit notwithstanding the adverse disparate impact.[22] This can be accomplished by showing that the challenged activity is necessary to meet a goal that is legitimate, important, and integral to the recipient's institutional mission.[23] The provision of public health or environmental benefits, as well as providing for economic development, are examples of acceptable justifications that the OCR may consider. Thus the ultimate disposition of an EJ complaint which challenges a permitting decision will rest on establishing that an unjustified, adverse, and disparate impact exists. That is, resolution depends on a showing of disparate-impact discrimination.

III. Documenting Disparate-Impact Discrimination

There is a substantial body of research over the past 30 years that attempts to document disparate-impact discrimination.[24] As a result of these efforts, significant progress has been made in addressing the methodological challenges posed by documenting that the environmental impacts associated with siting decisions may result

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[21] Title VI provides for a variety of options in the event that EPA finds a recipient in violation of the statute or regulations. The primary administrative remedy described in the regulations involves the termination of EPA assistance to the recipient (40 DFR 7.130 cal). Alternatively, EPA may issue other means authorized by law to obtain compliance (e.g. referral to the Department of Justice for judicial enforcement).

[22] Title VI guidance does not concern justifications for any violation of environmental law.

[23] See Donelly v. Rhode Island Bd. Of Governors for Higher Education, 929 F. Supp. 583, 593 (D.R.I. 1966), Aff'd on other grounds, 110 F. 3d 2 (1st Cir. 1997).

[24] An annotated bibliography of studies about racial and income disparities in environmental harms can be found in Cole and Foster (2000).

in unjustified, adverse, and disparate impacts on minority and/ or low-income communities.[25] This body of research has played a prominent role in focusing public attention on environmental justice issues and has helped shape legal responses as well. Unresolved, however, remains the issue of whether seeming disparities are better explained by other demographic factors (Rechtschaffen and Gauna, 2003).

The adverse impact of siting decisions has been documented in a variety of ways. Early studies such as Bullard (1993), the General Accounting Office (1983), and the United Church of Christ (UCC) (1987) found a consistent and high correlation between race and the location of treatment, storage, and disposal facilities (TSDF's).[26] The practice of measuring an adverse impact by measuring proximity to waste facilities, however, was subsequently criticized since it fails to account for the actual elevated levels of exposure (Boener and Lambert, 1995).

To account for exposure, more recent studies have used data from the Toxic Release Inventory (TRI) compiled and maintained by the EPA since 1981.[27] In a 1997 study, Ringquist accounted for the distribution of TRI facilities, the density of TRI facilities, and the associated concentration of emissions. The results supported the proposition that communities with large shares of African Americans and Hispanics suffer from significantly higher levels of TRI emissions. Similar results were reported in a study by Brooks and Sethi (1997). Two subsequent studies build on TRI exposure studies by evaluating the health effects of disparate exposure to environmental hazards. In a 1999 study, the Institute of Medicine's Committee on Environmental Justice found that minority and low-income communities not only experience higher levels of exposure but also are less able to manage them by obtaining adequate health care. Similarly, a recent study by Morello-Frosch (2001) estimated lifetime cancer risks for communities at

[25] A number of articles discuss methodological issues involved in environmental justice research including Boerner and Lambert (1995), Mohai (1995), Bullard (1983), Downey (1998), and Palido (1996).

[26] The Bullard study found that 21 of Houston's 25 solid waste facilities were located in predominately African American neighborhoods, even though African Americans made up only 28% of the Houston population in 1980. The GAO study found that three of the four major offsite hazardous waste facilities in the southern region (EPA Region IV) were located in predominately African American communities, even though African Americans comprised only about one-sixth of the region's population. The UCC study found in a national level study that race proved to be the most significant EJ explanatory factor among variables tested in association with the location of commercial hazardous waste facilities.

[27] Over 75,000 companies are required to report their emissions to the EPA by chemical, medium in which it is released, and amount released. Polluting facilities listed on the TRI outnumber waste facilities by almost 40 to 1 (see www.epa.gov/tri). Last accessed 7/2006.

risk and found that the likelihood of a person of color living in a high cancer risk community in Southern California was one in three as compared to approximately one in seven for predominantly white communities.

The most contentious issue involved in documenting that environmental siting decisions result in a disparate impact on minority or low-income communities is delineating the geographical extent of the impacted area.[28] An illustrative study in this regard is Cutter, et al. (1996). The study was conducted in South Carolina and found a positive association on the county level between percentage of black and low-income populations and the number of hazardous waste facilities. When the community was redefined by the geographical extent of the census tract, the correlation disappeared. As an applied matter, empirical studies have been conducted at the county level (Cutter, 1996), the zip code level (GAO, 1983), census tract level (Been and Gupta, 1997), and census block level (Cameron and Graham, 2004). Other studies have even employed complex definitions of community based on radial distances from TRI sites using geographical information systems and block level census data (Banzhaf and Walsh, 2005).[29] The common estimation problem for all studies attempting to document disparate impact is that the use of large geographic units may create aggregation errors by grouping neighborhoods with high minority composition together with neighborhoods of low minority composition. On the other hand, use of small refined definitions of community may significantly increase estimation cost and data requirements. More importantly, if units are too small, the area that is adversely impacted may extend well beyond the boundaries of the unit.[30] In practice, delineating the geographical extent of the impacts will be a matter of judgment, tailoring the definition of community to the environmental justice issue being investigated.

Finally, the issue of whether an adverse disparate impact is unjustified has been approached both retrospectively and prospectively. The empirical challenge is to

[28] The issue of defining the attributes that classify a person as "minority" or "low-income" can in itself become a debatable, even contentious issue. As a practical matter, the decennial census conducted by the U.S. Bureau of the Census remains the most widely used source of data to characterize populations based on race or ethnicity. Low-income populations are generally defined in relation to poverty thresholds such as the annual statistical poverty thresholds from the bureau of the Census current population reports series P-60 on income and poverty (Warren, 1999).

[29] See Fahshender for a survey of the social scene literature on various approaches to community definition.

[30] Mohai (1995).

determine if the disparate impact revealed in a variety of previous studies is due to the siting of LULU's or to subsequent changes in the minority/income composition of the host communities. That is, the possibility that siting decisions were chosen in a manner that was neither intentionally discriminatory nor discriminatory in effect, but that market responses to the facilities led the host neighborhoods to become disproportionately populated by the poor and by minorities must be examined. [31]

Been and Gupta (1997) examined these issues for the siting of TSDF's using census tract data. Retrospectively, the study provided no support for the proposition that TSDF's were sited in communities that had disproportionately high percentages of African Americans at the time of the siting, but did support the claim that the siting process was affected by the percentage of Hispanics in potential host communities.[32] Prospectively, the study found no support for the theory that the presence of a TSDF makes the host neighborhood less desirable because of the nuisance and risks the facility posed, which would cause property values to fall, making the community more affordable for low income and minority populations. To the contrary, the analysis indicated that the areas surrounding the TSDF's tended to be growth areas, suggesting that the costs of the TSDF were being offset by economic development benefits.[33]

In documenting whether the adverse disparate impacts which result from a siting decision are justified, the policy issue is prospective in nature. Title VI plaintiffs who prove disparate-impact discrimination are limited to prospective relief (Mank, 1999).[34] Compensatory relief is available only to plaintiffs who prove intentional discrimination. In EJ cases alleging disparate-impact discrimination, prospective relief would be limited to the voidance or relocation of a proposed facility and to the prevention of future harm. Thus the estimation issue is not simply whether past siting decisions were discriminatory.

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[31] Been (1994).

[32] The analysis also provided no support for the notion that neighborhoods with high percentages of poor are disproportionately chosen as sites. Working class or lower middle class neighborhoods located near industrial activity tend to bear a disproportionate share of TSDF's facilities. Similar findings were reported by Boer et al. (1997).

[33] Other studies have offered alternative explanations for host neighborhoods becoming disproportionately populated by the poor and by minorities. Pastor et al. (2001) argue that demographic shifts in these communities are better explained by general population trends. Banzhaf and Walsh (2004) found evidence that Tiebout sorting and differential migration best explain this phenomenon.

[34] Prevailing Title VI plaintiffs are also entitled to reasonable lawyers' fees. See Civil Rights Attorney's Fees Awards Act of 1976, 42 U.S.C. § 1988(6).

The issue is whether there is evidence that economic development benefits compensated for environmental risks in host communities, and whether such a trend can be expected to continue.

IV. The Arizona Experience

A successful environmental justice legal argument provides evidence that a minority or low-income community is suffering from an adverse, disparate, and unjustified impact as a result of TRI siting. To evaluate the EJ experience in Arizona, it is necessary to determine *(1)* if polluting facilities are disproportionately sited in areas with high concentrations of minorities, thus creating an adverse disparate impact, *(2)* if the causality can be reversed with the presence of polluting facilities partially accounting for the high concentrations of minority residents in exposed communities, and *(3)* if this relationship does exist, to what extent is the minority population actually migrating to these polluted areas. The region under investigation is the Phoenix Metropolitan area.

A. Background on Maricopa County, Arizona

The geographic scope of this study is Maricopa County, Arizona, which is home to the major metropolitan areas of Phoenix, Mesa, and Tempe as well as the Gila River and Salt River Pima-Maricopa Indian Communities and covers an area of over nine-thousand square miles. In the year 2000, Maricopa County was home to 3,072,149 residents – an impressive 44.8 percent increase from 1990 – of which 3.6 percent were African American, 1.8 percent were Native American or Alaska Native, and 24.9 percent, up about 10 percent from 1990, were Hispanic, which was the only minority group to significantly increase its share in the population over the decade.[35]

The NRDC (2004) study noted that 66 percent of Hispanics live in regions that fail to meet federal air quality standards including Phoenix, Chicago, New York, Houston, California's Central Valley, and the U.S.–Mexico border region. In the case of

[35] It is worth noting here that the birth rate among Hispanics is about 3 percent higher than the national average and about 4 percent higher than Whites. So although some of the 10 percent increase in the share of Hispanics can be attributed to a higher than average birth rate, it is not the only driver for their increased share in the population. See the National Vital Statistics Reports, "Estimated Pregnancy Rates for the United States, 1990 to 2000: An Update." Vol 52, Number 23. www.cdc.gov/nchs/data/nvsr/nvsr52/nvsr52_23.pdf. Last accessed 07/16/2006.

Phoenix, this result is not totally unexpected. The City of Phoenix is home to some of the most congested roads in the U.S.[36] and Maricopa County violates air quality standards for carbon dioxide, ozone, and particulate matter. The community of South Phoenix is 60 percent Hispanic and it has the highest asthma rate in Maricopa County. It is estimated that 25 percent of the children in the neighborhood's Roosevelt Elementary School District suffer from asthma (Quirindongo et al. 2004).

B. Establishing a Relationship between Minorities and Pollution

The relationship between pollution and minorities is complex. To test for the presence of an adverse disparate impact on low-income and minority communities, a retrospective perspective is adopted. Using data from 1990 and 2000, the factors influencing TRI facility location are estimated using a probit model to determine if there is a disproportionate number of facilities sited in or near minority communities. Next, to evaluate whether adverse disparate impacts from TRI siting, if any, are also unjustified, the causality is reversed to establish if the presence of these facilities partially explain the share of minorities in the surrounding neighborhoods, suggesting that areas surrounding TRI's tended to be growth areas with offsetting economic development benefits. The results from these initial estimations establish the nature of the ongoing interdependent relationship between pollution and minorities. A third simultaneous model is then estimated to better account for the possibility of an interdependent relationship, and to correct for potential bias and inconsistency issues in the estimates. Finally, from a prospective perspective, the shift in the population is estimated to determine if the minority population in Maricopa County actually migrated toward these TRI sources from 1990 to 2000.

Modeling TRI Siting Impacts. A probit equation is estimated to explain a facility's presence in a community. The presence or absence of a facility is regressed on the share of minorities in the community (SHMIN) as well as income levels (INCOME), housing variables, (RENT, OWN), educational attainment levels (NO_DIPLOMA, DIPLOMA,

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[36] Phoenix was ranked 14th in the U.S. in hours spent in traffic congestion per year. See D. Schrank and T. Lomax, Texas Transportation Institute, "The 2003 Annual Urban Mobility Report" available at http://mobility.tamu.edu/ums/. Last accessed 7/2006.

DEGREE), variables measuring the population density in the community (DENSITY), and occupation proxy variables to determine if residents work in the same community where they live (MANUFCTG, COMMUTE).[37] Tables 1 and 2 list variable definitions and descriptive statistics, respectively.

Reversing the Causality. After modeling the TRI siting impacts, the causality is reversed and this time the share of minorities (SHMIN) in each community is regressed on the presence of pollution (EXPOSURE) and emission levels weighted by toxicity (EMISSIONS), while controlling for housing values in the community (HOUSEVALUE, RENT, OWN), population density in the community (DENSITY), and occupation proxy variables (MANUFCTG, COMMUTE). Instead of a binary decision, a continuous measure of the share of a community's minority population is the dependent variable so that a linear regression model is appropriate.[38, 39]

Simultaneous Estimation. Estimating these equations separately provides the basic framework for the empirical piece of the environmental justice argument, but since the hypothesis in this case is not only that a relationship between minorities and pollution exists, but that the relationship is interdependent, a system of equations which

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[37] A generalized formulation of the probit proposed by Harvey (1976) is used which includes a correction for heteroscedasticity. This version of the probit accounts for a nonconstant variance by specifying the variables, x, suspected to cause heteroscedasticity, z, so that the variance of the error term becomes $Var[\varepsilon \mid x, z] = [\exp(z'\gamma)]^2$ (Greene 2003 pp. 680). When $\gamma = 0$, there is no heteroscedasticity and the standard probit model is obtained. Additionally, in an attempt to mitigate the simultaneous equations bias, right hand side variables are lagged. The binary dependent variable, EXPOSURE, measures the presence (Exposure = 1) or absence of exposure from 1995 and the explanatory variables are from 1990.

[38] Usually when the dependent variable is bound between 0 and 1, as it is here, a log of odds ratio model would be best. However, since in this sample there are communities that have both 0 and 100 percent minority populations, the log of odds ratio model is undefined. An alternative is to use a two-limit Tobit model . A total of 296 block groups, representing 7% of the sample, have no minorities. Additionally, 38 block groups, representing 0.90% of the sample, are inhibited only by minorities. A two-limit Tobit model is not used because it severely complicates the estimation of the simultaneous model presented later and the benefits of using a Tobit in this case may not be high.

[39] Heteroscedasticity is a likely problem in cross sectional data like the one used in the present study. To check for heteroscedasticity, Bruesch-Pagan-Godfrey test statistics are calculated. The calculated test statistics of 274.47 and 190.17 for 1990 and 2000 data, respectively, are bigger than the critical value of $X^2_{.05}(3)=7.815$ indicating a presence of heteroscedasticity. Therefore, a Feasible Generalized Least Squares (FGLS) procedure is used for estimating model parameters. As in the probit model, potential endogenous variables, EXPOSURE and EMISSIONS, are lagged to mitigate problems of simultaneous bias. The dependent variable, SHMIN, is the minority shares for year 2000 and EXPOSURE and EMISSIONS are for year 1995.

includes both of these models simultaneously will provide more reliable estimates.[40]

The simultaneous model used for explaining the siting decision and reverse causality is given by:

$$(1)\quad EXPOSURE_{it}^{*} = b_0 + b_{00} \cdot DUM2000_{it} + b_1 \cdot MANUFCTG_{it} + b_2 \cdot INCOME_{it} + b_3 \cdot RENT_{it} + \gamma_1 \cdot SHMIN_{it} + u_{1it},$$

where

$$EXPOSURE_{it} = \begin{cases} 0 & \text{if } EXPOSURE_{it}^{*} \le 0 \\ 1 & \text{if } EXPOSURE_{it}^{*} > 0 \end{cases}$$

and

(2)

$SHMIN_{it}=c_0+c_{00}\cdot DUM2000_{it}+c_1\cdot OWN_{it}+c_2\cdot DENSITY_{it}+\gamma_2\cdot EXPOSURE_{it}^{*}+u_{2it}$,

Where $_i$ represents households ($_i$=1,2, …,2105), $_t$ represents year ($_t$=1990, 2000), ($b_0, b_{00}, b_1, b_2, b_3, c_0, c_{00}, c_1, c_2, \gamma_1, \gamma_2$ are parameters to be estimated, u_{1it} and u_{2it} are disturbance terms and *DUM2000* is an indicator for year 2000 and other variables are as given in Table 1. The structural model given in equations (1) and (2) is simultaneous with unobservable endogenous variable on the right hand side of (2).[41] An estimation procedure should account for this simultaneity and possible correlation between u_1 and u_2 to obtain consistent and efficient parameter estimates.[42]

Estimating the Migratory Effects of Pollution. A fourth and final model is estimated to measure the shifts in population from 1990 to 2000 in an attempt to answer the question posed by Been and Gupta (1997) and also explored by Banzhaf and Walsh (2004): are racial and ethnic minorities migrating toward the pollution? Changes in community

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[40] Using least squares to estimate the parameters in the equations separately could result in inconsistent estimates because the variables on the right-hand side are endogeneous and correlated with the disturbance terms (Greene 2003). The use of lagged variables in the previous two models does mitigate the effect of endogeneity; however, the joint model better addresses the endogeneity problem while also accounting for contemporaneous correlation between u_1, and u_2.

[41] A simultaneous model with observed binary variable, EXPOSURE, instead of unobservable $EXPOSURE^*$, on the right hand side of (2) is internally inconsistent and cannot be estimated unless γ_1=0 or γ_2=0. See Maddala, pages 117-118.

[42] Appendix A provides the interested reader with details of this estimation procedure. Also see Greene pages 378 – 382.

Table 1: List of Variables Used in the Study.

COMMUTE	Percent of people in a community who commute 15 minutes or less to work
DEGREE	Share in each community whose highest level of education is a Bachelor's Degree
DELTA "D"	Calculated by subtracting the 1990 data from 2000
DENSITY	Total population for each block group divided by the total square miles for each block group
DIPLOMA	Share whose highest level of education is a high school diploma
EMISSIONS	The hazard score is calculated by the EPA's RSEI model and weights emissions by multiplying the annual pounds released by a risk score.
ENTRANCE	A dummy variable taking the value of "1" if a community has gone not exposed in 1990 to exposed in 1995.
EXIT	A dummy variable taking the value of "1" if the block group has gone from exposed in 1990 to not exposed in 1995.
EXPOSURE VARIABLES	A dummy where a "1" indicates the community is exposed to a TRI within one mile and a "0" otherwise for 1990, 1995, and 2000.
HV	Median self-reported house value for each community
INCOME	Median household income for each block group
MANUFCTG	Share of people in the work force in each community who work in the manufacturing industry for both durable and non-durable goods.
NO _DIPLOMA	Share of people in each block group over the age of twenty-five who have completed some high school but have not received a diploma.
OWN	Percent owning their homes out of total occupied housing units
POVERTY	Percent of people living below the poverty level in a block group
RENT	Median rent paid for renter occupied housing in a block group
SHMIN	Share of each minority (African American, Native American, and Hispanic) is summed for each block group for 1990 and 2000.

Note: DINCOME, DHV, and DRENT are calculated using the Implicit Price deflators for GDP as provided by the Bureau of Economic Analysis using Tab1e.1.1.9.
http://www.bea.gov/bea/dn/nipaweb/TableView.asp?SelectedTable=13&FirstYear=1988&LastYear=2006&Freq=Qtr. Last accessed on 7/16/2006.

Table 2: Descriptive Statistics for 1990 and 2000 Block Groups

Label	Summary for 1990		Summary for 2000	
	Mean	Std Dev	Mean	Std Dev
SQKILO	11.28	137.79	11.28	137.79
POPULATION	2007.66	46,137.3	2906.48	66793.43
DENSITY	4472.75	3572.3	5738.33	4307.70
SHWHITE	.833	.222	.764	.205
SHBLACK	.031	.068	.036	.055
SHNATIVE	.017	.060	.019	.054
SHASIA	.015	.026	.022	.0333
SHHISP	.152	.189	.249	.247
SHMIN	.200	.231	.303	.276
INCOME	33.5	18.18	47.8	23.9
POVERTY	.118	.135	.121	.130
OWN	.645	.300	.669	.295
RENT	5.27	2.59	7.43	3.65
HOUSEVALUE	85.1	54.6	122.8	92.2
EMISSIONS	731	26,613	34,298	538,719
EXPOSURE (0,1)	0.20	0.40	0.25	0.44
MANUFCTG	.138	.080	.112	.071
COMMUTE	.251	.139	.236	.119
NO_DIPLOMA	.118	.085	.108	.083
DIPLOMA	.266	.115	.232	.097
DEGREE	.151	.113	.155	.109
Delta Variables 1990 – 2000				
DMIN			.089	.161
DDENSITY			1266	2119
DRENT			.391	4.11
DHV			9.21	64.56
DMANFG			-.026	.091
DCOMMUTE			-.015	.149
DEMISSIONS			16287	354035
ENTRANCE			0.04	0.20
EXIT			0.07	0.25

composition are examined with an FGLS model estimated in SAS, regressing the *change* in the minority population from 1990 to 2000 (DMIN) on the *change* in pollution from 1990 to 1995 (DEMISSIONS, ENTRANCE, EXIT, EXPOSURE90) as well as the *change* in housing values (DHV, DRENT), population density (DDENSITY) and employment variables (DMANFG, DCOMMUTE).[43]

C. The Data

Although environmental justice concerns both racial and ethnic minorities as well as low-income communities, race is the principal focus of this study since it is highly correlated with poverty and is consistent with much of the EJ literature. Also, since Hispanics comprise almost all of the minority population in Maricopa County where Native Americans and African Americans account for only two and three percent respectively, they are grouped together to represent the overall minority share.

Data for the empirical work that follows comes from two main sources: the U.S. Census from 1990 and 2000 at the block group level for demographic and socioeconomic measures, and the Toxic Release Inventory (TRI) compiled and maintained for the public by the U.S. EPA as a measure of environmental quality. The TRI data is attached to "communities" which are defined using block group boundaries from the U.S. Census.

Community Definitions. For this study, community is defined as a U.S. Census block group. The use of larger geographic units such as census tracts would tend to create aggregate errors by grouping neighborhoods with high minority composition together with neighborhoods of low minority composition. Analysis at the block group level

[43] Again the Breusch-Pagan/Godfrey LM test is conducted; the test statistic is 16.73 and the critical value for $\chi^2_{.05}(3)$ is 7.815; therefore, reject the null of homoscedasticity and proceed with FGLS as an OLS model would be misspecified. Additionally, as Banzhaf and Walsh (2004) note, if polluters are indeed making discriminatory siting decisions, measuring a shift in the minority population that is spurred by pollution may cause endogeneity problems; therefore, the pollution variables for 2000 (DEMISSIONS, ENTRANCE, EXIT) are lagged to 1995 levels. Although the lagging will not completely eliminate the problems of endogeneity, it does mitigate the effects of endogeneity on the parameter estimates.

provides greater resolution than at the tract level without sacrificing relevant information publicly provided by the U.S. Census.[44]

One problem with using block groups is the shifting of block group boundaries from Decennial Census to Decennial Census, making it difficult to compare community characteristics across time periods. To solve the problem, Geolytics developed the Neighborhood Change Database (NCDB) [45] which aggregates the 1990 U.S. Census block group and census tract boundaries to the 2000 levels. Using Geolytics' NCDB package, there are a total of 2,113 block group communities for both 1990 and 2000 in Maricopa County after the boundary adjustment.

Figures 2 and 3 provide maps of Maricopa County including the block group boundaries aggregated to the 2000 levels. The maps are overlaid with the mean percent of Hispanics per each block group for 1990 (Figure 2) and 2000 (Figure 3) and also with the top 25[*] polluting TRI facilities for each time period. It is clear from the maps that communities with high percentages of Hispanics also tend to be in close proximity to a TRI facility. Interestingly, a comparison of the maps, suggests that the areas with TRI facilities become more Hispanic from 1990 to 2000. [46]

Toxic Release Inventory and Emission Levels. The EPA's Toxic Release Inventory (TRI) is used in this study as a measure of environmental quality. The TRI was developed by the EPA in 1987, under the umbrella of the Emergency Planning and Community Right-to-Know Act of 1986 (EPCRA).[47] The EPCRA requires facilities releasing significant

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[44] One drawback of using either block group or census tract as a community definition is variation in size. For example in Maricopa County in 2000, the block groups range from about .08 square miles to 1,675 square miles, making it difficult to account for the "large degree of heterogeneity when estimating migration models" (Banzhaf and Walsh 2004 p.10). In 2000, population ranged from 0 to 14,658 people per block group with a mean of 1,454.

[45] For more information on NCDB see http://www.geolytics.com. Last accessed 7/16/2006.

[46] Among only the "exposed" communities, the share of Hispanics increased from 1990 to 2000 by about 15 percent, a rate 5 percent higher than the rest of the county. In 2000, the mean income among exposed communities was $42,029, 13.7 percent below the county mean, and the share of people living below the poverty level was 5% above the county average.

[47] See http://www.epa.gov/tri/tri_program_fact_sheet.htm.

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*There were 125 TRI facilities in Maricopa County in 1990 and 122 in 2000. Hazard scores-explained later-are used to identify the top 25 polluting facilities.

Figure 2. Top 25 TRI Facilities, 1990

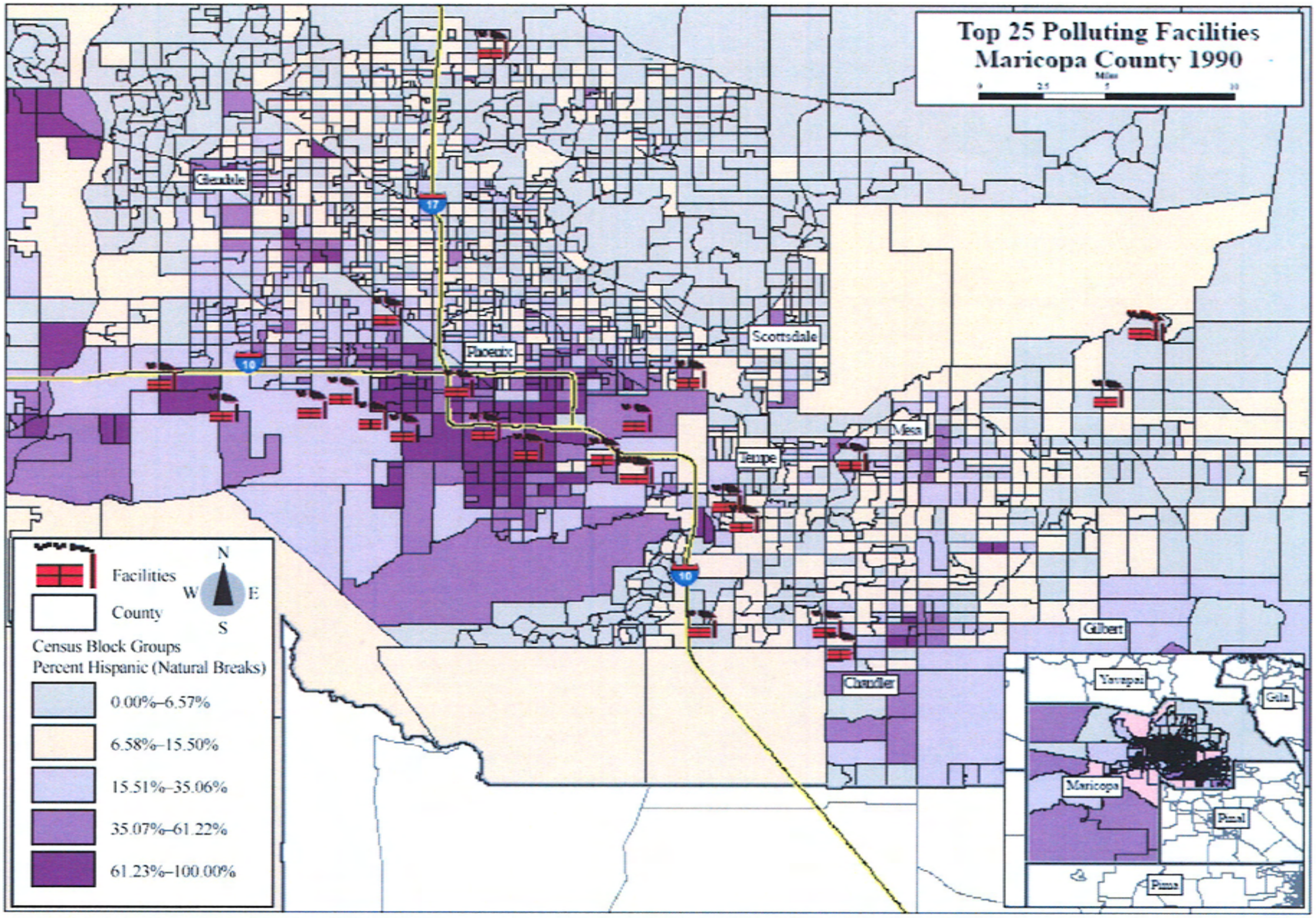
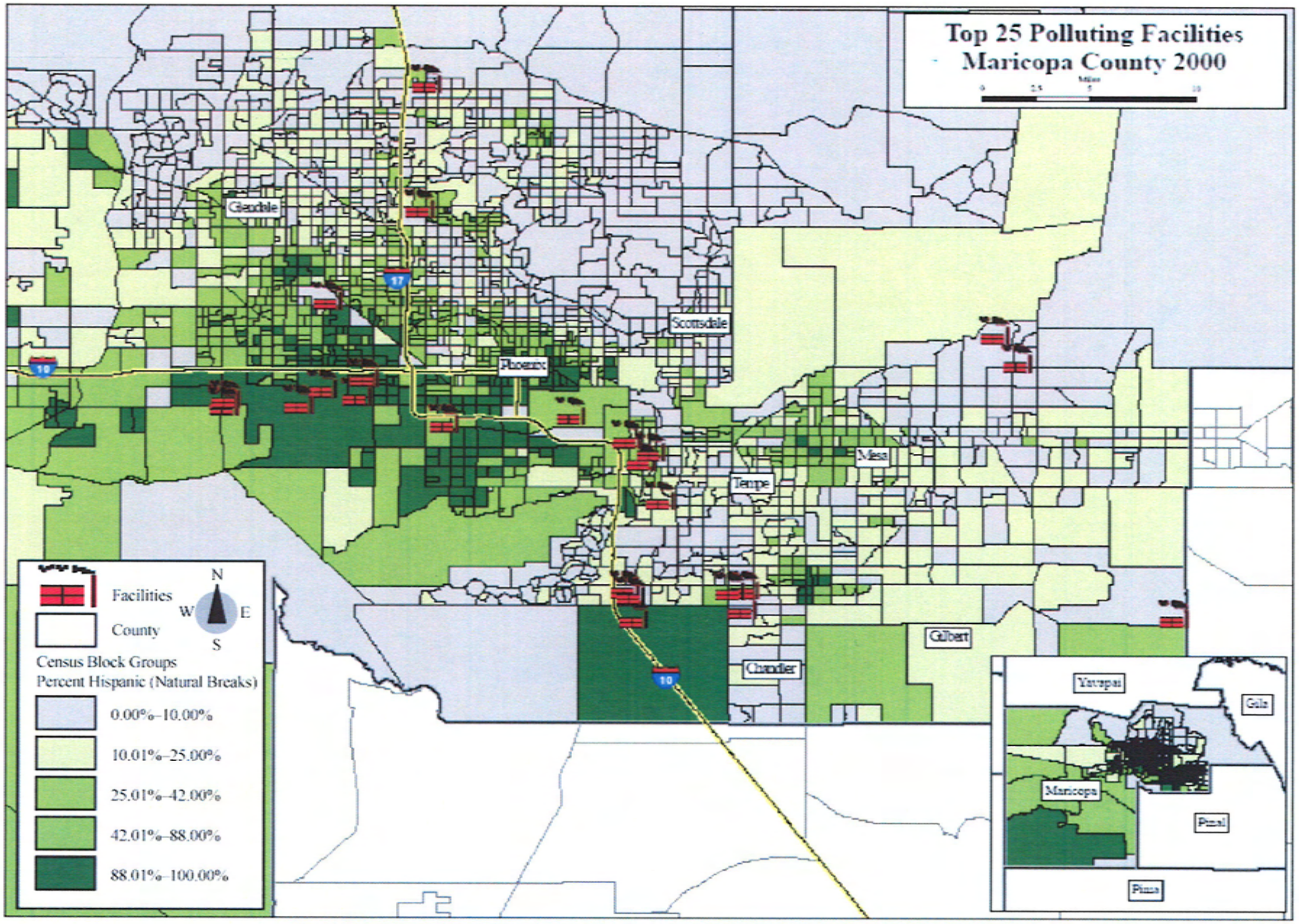


Figure 3. Top 25 TRI Facilities, 2000



amounts of various chemicals each year to report to the EPA. A database on these releases was subsequently initiated that is available to the public. Since the TRI is not a static program, new chemicals and industries have been added to the list of reporting requirements since its inception in 1987. For the empirical work that follows, only the 1988 required core chemicals were used as a measure of pollution to maintain consistency in reported chemicals from 1990 to 2000. There were 125 TRI facilities in Maricopa County in 1990, 99 facilities in 1995, and 122 facilities in 2000.

In order to measure a facility's impact on communities more accurately, emissions have been weighted by toxicity using the EPA's Risk-Screening Environmental Indicators[48] (RSEI) model which works in conjunction with the TRI. The RSEI assigns a "hazard score" to a facility's emissions by accounting for not only the amounts of chemicals released, but also for the environmental concentrations resulting from releases, doses that people receive from those concentrations, the relative chronic toxicity of those doses and the number of those affected.

In order to measure exposure not only of the communities hosting a TRI facility, but of the surrounding communities which may also be exposed, a one mile radius is constructed around each TRI facility.[49] To construct the buffers around each facility, first, using Geolytics' software, the latitude and longitude coordinates were entered for a facility.[50] Then a one mile radius is drawn around that point source of pollution. This is done one facility at a time for 1990, 1995[51], and then again for 2000. Any block group that is captured in that radius is considered "exposed" and assigned a "1" for the exposed indicator variable.

Next, emissions levels are assigned to each community. In order to "weight" the emissions for each community so that communities which are only exposed by a fraction are assigned fewer emissions than one that is entirely exposed, a variation of the above method is used. This time instead of using the block *groups* that are captured in the one mile radius, the smaller units of blocks are used. Since blocks are typically much smaller

[48] Information on the RSEI model can be found at http://www.epa.gov/oppt/rsei/.
[49] Banzhaf and Walsh (2004) similarly use a one mile then half mile radius "buffer" around facilities and found no significant difference between the two.
[50] The longitude and latitude coordinates are provided for each facility on the TRI and they have been cross-checked and corrected for the RSEI model.
[51] Exposure at the 1995 level was calculated to capture a lagged effect when examining the population change from 1990 to 2000.

than block groups, when the radius is constructed around the facility many blocks are captured in that radius, as opposed to only three or four block groups. Each block can then be matched to its block group. Exposure at the block group level is then calculated by summing the total square kilometers for each block exposed in the group and dividing it by the sum of the area of all exposed blocks within the radius of the facility. That fraction is then multiplied by the hazard score for that facility. This is repeated for each facility and for each time period. Hazard scores are summed for block groups exposed to multiple sources, so that the emissions for block group m (B_m) is given by:

$$(3) \qquad B_m = \sum_{i=1}^{125} (T_{mi}/T_i) \cdot S_i\,; \;\; m = 1, 2, \ldots, 2105$$

Where, T_{mi} = the total area of blocks in group m exposed to facility i, T_i = the total area of all blocks exposed to facility i, S_i = the hazard score for facility i.

D. Results

Results from the probit model, shown in Table 3, reveal a positive and highly significant relationship between TRI exposure and minorities, which is consistent with much of the EJ literature. There is also a positive and significant relationship at the 5 percent level between those employed in the manufacturing industry and TRI siting, indicating that there may be benefits by way of employment in these communities, both for residents and TRI facilities.

The relationship between low-income communities and TRI siting is suggestive but not demonstrative. As expected, income has a negative relationship with a facility's presence, but it fails to be a statistically significant predictor of TRI siting. Additionally, there is inconclusive evidence of a nonlinear relationship between rent and the likelihood of a TRI siting since rent is positive but its squared term is negative; the squared term, however, is not significant. A nonlinear relationship would be consistent with Been and Gupta's (1997) findings that TSDF's were often sited in working class neighborhoods and were actually repelled by very poor areas that lack the infrastructure to support such a facility.[52]

Since there are many considerations taken into account when siting a facility and they are not all represented here, it is inappropriate to conclude that these siting decisions were made in a discriminatory fashion, either by the owner/operators of the facility or by the relevant permitting agencies, but the model does reveal that there is a relationship between high concentrations of minority residents and TRI siting even when controlling for income, occupation, and education.

The results shown in Table 4 for the FGLS model reveal a relatively high adjusted R^2 of .446 for cross sectional data[53] and document that the presence of a facility is a positive and significant predictor at the 5 percent level for the share of minorities in a community – the presence of a TRI facility increases the minority share by 9.6 percent. Interestingly, the level of emissions is not significant indicating that the mere presence of a facility, regardless of the hazard level or amount it is emitting, is a predictor of a high-minority share in a community.[54] The share of people working in their communities or neighboring communities (COMMUTE) is also significant predictor of increased minority share just as it predicted TRI siting decisions in the probit model. Additionally, the share of those in manufacturing jobs is positive and significant, which provides support for the proposition that those jobs are close to home for minority residents. These results provide further evidence for conclusions posited by Been and Gupta (1997) who argue that the employment benefits of a TSDF may outweigh the costs.[55]

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[52] Another interesting and unexpected result comes from the educational attainment variables. A 5.5 percent increase in residents with college degrees increases the probability of exposure by 10 percent; whereas, the other educational attainment variables proved to be insignificant predictors of exposure.

[53] The R^2 could be improved with the addition of variables capturing other attributes of a community that make it attractive to racial and ethnic minorities like proximity to bilingual schools and churches, or to public transportation. A survey of people in the region would best capture other reasons for choosing one community over another like sentimental attachment, family connections, or common language among the community.

[54] Banzhaf and Walsh (2004) find similar results in their California study.

[55] As expected, housing values, rent, and share of homeowners in a neighborhood (HOUSEVALUE, RENT, OWN) are all negative and significant indicators of minority share, indicating that there is a significant relationship between community property values and minority location decision making.

Table 3: Maximum Likelihood Estimates of Probit Model forTRI Siting Impacts

Variables	Estimates	Standard Error	t value	Marginal Effects
SHMIN	0.673**	0.267	2.520	0.423
OWN	-0.2180*	0.121	-1.800	-0.137
RENT	0.126**	0.058	2.160	0.079
RENTSQ	-0.007	0.005	-1.430	-0.004
INCOME	-0.003	0.003	-1.010	-0.002
DENSITY	-0.003	0.006	-0.420	-0.002
NO_DIPLOMA	0.200	0.327	0.610	0.126
DIPLOMA	0.228	0.255	0.890	0.143
DEGREE	0.878*	0.515	1.710	0.552
MANUFCTG	1.129**	0.577	1.960	0.710
COMMUTE	0.248	0.148	1.670	0.156
CONSTANT	-1.345**	0.378	-3.560	

Note: The dependent variable is EXPOSURE for year 1995**Statistically significant at the 5% level or better. *Statistically significant at the 10% level. The explanatory variables are for 1990 to mitigate possible simultaneous equation bias.

Table 4: FGLS Estimation Reversing the Causality

Variables	2000 Estimates	Standard Error	t value
EXPOSURE	0.096**	0.012	8.13
EMISSIONS	-1.92E-12	1.30E-11	-0.15
HOUSEVALUE	-3.43E-04**	4.83E-05	-7.11
RENT	-0.022**	0.001	-19.1
OWN	-0.100**	0.019	-5.18
MANUFCTG	0.534**	0.057	9.38
COMMUTE	-0.123**	0.035	-3.49
DENSITY	0.015**	0.001	13.24
CONSTANT	0.391**	0.020	19.7
R-Squared			0.4461
Observations			2105

Note: The dependent variable is SHMIN. ** Statistically significant at the 5% level or better.

The results from the joint model, shown in Table 5, do provide strong evidence of an interdependent relationship between the minority community and TRI pollution as many of the results from the previous two models are reinforced. Exposure is a strong, positive predictor of minority share at the 99 percent level, and minority share is also a positive, significant predictor of exposure. Homeownership and rent maintain their negative relationship with minority share as does income with exposure – all at the 5 percent level of significance. High shares of manufacturing jobs continue to be positively correlated with exposure again at the 5 percent level of significance and minorities maintain a positive relationship with population density. These results support the contention that the decision to build a plant and the decision to remain in a particular exposed community are not isolated but an interdependent system of preferences that influence each other.

Results from the migration equation are presented in Table 6. The results establish that when a facility enters a community in 1995 that was previously not exposed, the share of minorities will subsequently increase by nearly 3 percent in 2000. The opposite is true if a community switches from exposed to not exposed -- when a TRI facility exits a community in 1995, the share of minorities in that area decreases over 3 percent by the year 2000. Given exit or entry into a community, the share of minorities in a community tended to decrease as the level of emissions adjusted for toxicity increased, while lower housing values and rents were negative and significant indicators of a change in minority share. Finally, employment variables were positive as expected but not significant. Recall from the first two models that a high percentage of manufacturing jobs and a high percentage of workers with a short commute in a community were significantly correlated with both TRI facilities and high concentrations of minorities. When modeling the change in community composition, however, these employment considerations exert a statistically insignificant influence on location decision making.

Table 5. Maximum Likelihood Estimates of the Simultaneous Model

Variable	Estimate	Standard Error	t value
TRI Siting Equation (Probit Model, Dependent Variable: EXPOSURE):			
INTERCEPT	-9.295E-01**	1.071E-01	-8.676
DUM2000	2.293E-01**	1.044E-01	2.196
MANUFCTG	1.100E-02**	5.492E-03	2.004
INCOME	-4.614E-03**	2.333E-03	-1.977
RENT	-1.461E-04**	7.430E-05	-1.966
SHMIN	9.237E-03**	4.532E-03	2.038
Share of Minorities Equation (Dependent Variable: SHMIN):			
INTERCEPT	5.631E+01**	4.268E+00	13.194
DUM2000	-6.485E-01	3.084E+00	-0.210
OWN	-3.740E-02**	1.767E-02	-2.117
DENCITY	5.233E-04**	2.291E-04	2.284
EXPOSURE*	4.481E+01**	5.454E+00	8.215
Value of Log-likelihood	-17151.9		
Sample Size	4226		

** Statistically significant at 5% level.

Table 6: FGLS Estimation of the Migration Effects

Variables	Estimates	Standard Error	t value
DEMISSIONS	-1.64E-06**	4.54E-07	-3.610
ENTRANCE	2.804*	1.651	1.700
EXIT	-3.344**	1.557	-2.150
EXPOSURE90	4.086**	0.989	4.130
DHV	-0.027**	0.006	-4.630
DRENT	-0.654**	0.136	-4.820
DDENSITY	2.284**	0.160	14.260
DMANFG	2.988	3.684	0.810
DCOMMUTE	1.314	2.146	0.610
CONSTANT	5.752**	0.441	13.050
R-squared			0.1082
Observations			2105

Note: The dependent variable is DMIN. **Statistically significant at the 5% level or better. *Statistically significant at the 10% level.

E. Conclusions of Empirical Research

This paper uses a simultaneous equations model for jointly explaining firm's siting decision and minorities' decision to relocate. This is one of the first applications of such a simultaneous model in the EJ literature. By simultaneously estimating the siting and relocation equations, the model accounts for a two-way causality often ignored by single equation estimation technique. Thus, the simultaneous model estimated in this study gives estimates that mitigate the bias associated with single equation estimation and the resulting policy implications from the model are more robust.

Two conclusions emerge from this empirical work. First, TRI facilities in Maricopa County have been disproportionately located in areas with high minority concentrations; that is, the hypothesis that TRI facility siting has resulted in an adverse and disparate impact on minority communities cannot be rejected. Second, the presence or addition of a TRI facility increased the minority share in a community by nearly 10%. Additionally, communities with TRI facilities tended to have a higher share of people in the work force who worked in the manufacturing industry for both durable and non-durable goods and had a higher percentage of people who commuted 15 minutes or less to work. These results support the proposition that areas surrounding TRI facilities tended to be growth areas with the costs of increased exposure being offset by economic development benefits. That is, the assertion that the adverse disparate impacts generated by TRI siting were justified can also not be rejected.

V. Principles of Distribution, Environmental Justice, and TRI Facility Siting

Based on the available evidence, TRI facility siting in the Phoenix Metropolitan Area over the 1990 to 2000 period resulted in adverse, disparate, but justified impacts on minority communities. That is, the siting of these facilities increased exposure to toxic emissions disproportionately in minority neighborhoods, but also generated economic benefits by contributing to an overall environment that helped create growth areas in the region. The fact that TRI facility siting has tended to generate both heightened environmental risks and economic development benefits creates a fundamental policy dilemma: how should future TRI permitting applications be evaluated? Surprisingly, conventional notions of fairness, frequently advanced in EJ settings, offer little, if any, guidance in this regard.

A. Deontological Principles of Distribution and the Pareto Principle

In 2001, Kaplow and Shavell (KS) established an important and striking result for the evaluation of legal rules; namely, any method of policy assessment that is not purely welfarist violates the Pareto principle. That is, any conceivable notion of social welfare that does not depend solely on individuals' utilities will sometimes require adoption of a policy that makes everyone worse off. This theme was subsequently elaborated on in Fairness versus Welfare (2002) where the authors concluded that:

> "…legal policy should be evaluated using the framework of welfare economics, under which assessments of policies depend exclusively on their effects on individuals' well-being. … In arguing that no evaluative importance should be given to notions of fairness, we are criticizing principles that give weight to factors that are independent of individuals' well-being or its overall distribution. … pursuing notions of fairness comes at the expense of individuals' well-being. Indeed, giving weight to any notion of fairness entails accepting the conclusion that it may be good to adopt legal rules under which literally everyone is made worse off."[56]

This critique applies with particular force to notions of fairness frequently employed in the context of environmental justice. As the results of the Phoenix Metropolitan Area study document, TRI siting involves tradeoffs between economic development benefits and environmental risks. Conventional notions of fairness are ill-

[56] Kaplow and Shavell (2002), p.p. 465-466.

equipped to evaluate siting permit petitions under these circumstances. In fact, the application of these notions may well result in counterproductive, even paradoxical outcomes, making both candidate host communities and owner/operators of TRI facilities worse off.

B. Notions of Fairness and TRI Facility Siting

In discussing environmental justice, it is common to distinguish between procedural and substantive justice. Procedural justice is concerned with due process and equal protection under the law, emphasizing meaningful involvement in environmental decision making. Substantive environmental justice, on the other hand, is concerned with the distribution of environmental benefits and burdens.[57] In the context of TRI facility siting, the challenge is to develop a principle of distribution that can address the issue of disproportionate exposure of minority communities to environmental hazards, toxics and pollution. Three notions of fairness have played a prominent role in discussions of these concerns.

Right to Environmental Protection. In defining environmental justice, the U.S. Environmental Protection Agency asserts that no group should bear a disproportionate share of negative environmental consequences. The emphasis on disproportionate impact characterized much of the early environmental justice literature. Robert Bullard, widely regarded as one of the pioneering researchers and a leading scholar in this area, has argued that environmental justice requires going beyond concern for disproportionate impacts. A workable environmental justice framework must incorporate the principle of the right of all individuals to be protected from environment degradation:

> "Unequal protection needs to be attached via a Fair Environmental Protection Act that moves protection from a 'privilege' to a 'right.' … From this critical vantage point, the solution to unequal environmental protection is seen to lie in the struggle for justice for all Americans. No community, rich or poor, black or white, should be allowed to become an ecological 'sacrifice zone.' … Our long-range vision must also include institutionalizing sustainable and just environmental practices that meet human needs without sacrificing the land's ecological integrity."[58]

[57] As Bell (2004) points out, procedural justice may be intrinsically valuable by furthering substantive environmental justice goals. The concern here, however, is with substantive environmental justice exclusively and the underlying distributive principles that may promote it.

[58] Bullard (1993), as excerpted in Rechtschaffen and Gauna (2003), p.p. 417-419.

Basing environmental justice on this notion of fairness requires that entities applying for operating permits (e.g. landfills, incinerators, smelters, refineries, chemical plants, etc.) not only document that their operations will not disproportionately impact racial and ethnic minorities, but also prove that their operations are not harmful to human health.

Principle of Prima Facie Political Equality. In a recent contribution to the environmental justice literature, Shrader-Frechette (2002) argues that to correct problems of environmental justice, it will be necessary to improve the principles and practices of distributive justice, where distributive justice requires adopting social policy that promotes an equal apportionment of social benefits and burdens. Specifically,

> "Arguing … for a principle of political equality, but admitting that sometimes good reasons may justify treating groups differently, is arguing for a principle of prima facie political equality. The PPFPE presumes that equality is defensible and that only different or unequal treatment requires justification, that the discriminator bears the burden of proof. Not to put this burden on the possible discriminator would be to encourage power, rather than fairness, to determine treatment under the law. Two of the goals of the PPFPE are to help ensure equal distribution of environmental impacts and to place the burden of proof on those attempting to justify unequal distribution."[59]

In this ethical framework, equality of treatment does not require giving everyone the same treatment. In the context of minority communities and disproportionate environmental risk, the imposition of unequal environmental burdens would not violate the PPFPE if there were morally relevant reasons for different treatment or if the interests of one group were "correctly" judged to outweigh those of another.

The Difference Principle. In his classic analysis of justice, John Rawls (1971) argues that society should adopt a set of political, economic, and social institutions that guarantees each individual the same unassailable claim to a fully adequate scheme of equal basic liberties and that:

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[59] Shrader-Frechette (2002), p. 27.

> Social and economic inequalities are to satisfy two conditions: First, they are to be attached to offices and positions open to all under conditions of fair equality of opportunity; and second, they are to be to the greatest benefit of the least-advantaged members of society (the difference principle).[60]

In a recent contribution to the environmental ethics literature, Bell (2004) argues that the difference principle can be extended to address substantive environmental justice concerns. This extension is predicated on the established link between environmental pollution and the degradation of health. In Justice as Fairness, Rawls (2001) addends health care to the list of primary goods, goods that are publicly recognized as citizens' needs and counted as advantageous for all, arguing that the aim of health care is to maintain and restore the minimum essential capacities for being a normal and fully cooperating member of society.[61] By extension then, environmental goods should be included on the list of primary goods since exposure to toxics, pollution and contamination is linked so closely to respiratory and carcinogenic illnesses.[62] Trading off the provision of environmental goods with other primary goods then becomes a matter of identifying least-advantaged groups, followed by an evaluation of the effects of alternative policy packages on citizens' essential capacities, based on as much empirical information as it is cost-effective for society to acquire.

Policy Assessment. None of these notions of fairness provides a reliable distributive principle for evaluating TRI facility-siting applications. By advocating the deontological pursuit of a right, equality, or a principle, no systematic tie to the actual well-being of community residents is established. Pareto-improving decision making would occur only by chance.

Advocates of a right to environmental protection frequently adopt an absolutist perspective. By insisting that no community should be harmed and all concerns redressed, attention can be deflected from serious hazards to less serious risk. No guidance is provided by this notion of fairness on how to set risk priorities, and failure to set environmental priorities may actually worsen the hazards faced by minority and low-

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[60] See Rawls (2001), p.p. 42-43.
[61] Rawls (2001), p. 172.
[62] Bell (2004), p. 298.

income communities.[63] Given this failing, it is clear that advocating a right to environmental protection cannot help much in the assessment of more complex risk/benefit tradeoffs.[64]

The pursuit of political equality, if taken literally, suggests an equal distribution of TRI facilities across the Phoenix Metropolitan Area is a *priori* defensible. Based on this regional perspective, approval of sites in communities where net benefits are negative, and denial of applications in neighborhoods where both the community and site applicants would be made better off, could not be ruled out.[65] From the more policy-relevant perspective of the communities that would actually be impacted by approval of a TRI facility-siting application, it is unclear what role "equal treatment" would play in evaluating the TRI siting request. Under the PPFPE, morally relevant reasons would have to be proffered to justify different treatment. To the extent that these reasons are non-consequentialist in nature, violations of the Pareto principle cannot be ruled out. To the extent these reasons are consequentialist and based on an assessment of community residents' well-being, PPFPE is simply inapposite. In the end, the PPFPE addresses procedural, not substantive environmental justice concerns.

Finally, it is unclear how an extension of the difference principle to environmental justice could be applied to the evaluation of site applications since the very definition of least-advantaged members of society will be unclear in many applications. The statistical evidence for the Phoenix Metropolitan Area suggests that the poorest, least-advantaged neighborhoods are not even candidates to be host communities due to inadequate infrastructure. Moreover, within many candidate communities, income and minority composition are relatively homogeneous, making meaningful distinctions between advantaged and least-advantaged residents difficult to delineate. For the remaining candidate host communities, where least-advantaged populations may be well defined, heterogeneous tastes for environmental risk and economic development are likely to characterize neighborhood residents. Under these circumstances, trading off one primary

[63] Nichols (1994), p. 268.
[64] See Foreman (1998), p.p. 115-121 for a discussion of this and related critiques.
[65] An alternative and more defensible principle of distribution from a regional perspective would be to distribute TRI facilities equimarginally, not equally, so that regional net benefits are maximized. As a practical matter, a neighborhood, not regional, perspective is required for evaluating site applications since permitting requests are community-specific due to infrastructure and input cost concerns.

good, environmental quality, for another primary good, economic opportunity, for a "representative" resident becomes empirically intractable, requiring the identification of tastes and preferences for affected groups, interpersonal comparisons of well-being between these groups, and the aggregation of these assessments across community residents. Establishing a coherent decision rule under these conditions is problematic at best, quixotic at worst. Moreover, the equitable allocation of primary goods may not be related in any systematic or predictable way to the well-being of community residents impacted by the TRI facility, the central environmental justice concern.[66]

C. A Welfarist Approach to TRI Facility Siting

A welfarist assessment of a TRI facility-siting application would be individualistic. That is, the assessment is based exclusively on the proposed facility's impact on the individual well-being of host community residents. Based on a positive economic analysis of the facility's effects on individuals, a normative analysis would then be conducted to determine its social desirability. Thus, a consequentialist, teleological perspective is adopted in this approach to distributive analysis. Predicated on an assessment of the facility's impact on individual well-being, as well as the concomitant distributive implications, information is aggregated across individuals to form an overall social judgment on the likelihood that approval of the application would be welfare-enhancing.

As an applied matter, conducting a normative economic analysis requires: 1) an evaluation of how individuals' utility or well-being will be affected; 2) an assessment concerning interpersonal comparisons of utility between the various members of the host community; and 3) the aggregation of this information across community residents to formulate a coherent social welfare assessment based on cogent distributive judgments. Each of these steps face formidable implementation obstacles.[67] More pragmatically, it

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[66] See Sumner (1996), p.p. 42-80.

[67] For example, aggregation of individuals' well-being into a single measure of social welfare is controversial and an area of normative economics that is largely unresolved. A variety of principles can govern distribution so disagreements about the nature of social welfare functions, and their alternative policy recommendations, will be the rule, not the exception. (See Sen and Williams (1982) for a survey; for a skeptical assessment, see Mishan (1981), p.p. 125-134). Similarly, construction of a notion of well-being that is interpersonally comparable and adequate for purposes of distributive justice is an unresolved conceptual issue in normative economics. Specifically, there is no unanimity among

seems unlikely that prescriptions from normative economic analysis could serve as a consensual basis for evaluating a contentious siting proposal:

> "… Even if general and comprehensive teleological principles were adopted as political principles of justice, the form of public reasoning they specify tends to be politically unworkable. For if the elaborate theoretical calculations involved in applying their principles are publicly admitted in questions of political justice, the highly speculative nature and enormous complexity of these calculations are bound to make citizens with opposing views and interests highly suspicious of one another's arguments. … The information they presuppose is difficult if not impossible to obtain, and often there are insuperable problems in reaching an objective and agreed assessment."[68]

Given the inherent complexity of a facility-siting controversy, immanent problems of conceptual and empirical indeterminancy in welfarist assessments, and the likely irreversibility of approving and subsequently building a TRI facility, advocating the use of normative economic prescriptions to evaluate siting applications seems simply untenable.[69]

VI. Summary and Policy Implications

A central theme of environmental justice is concern over the disproportionate exposure of low-income and minority communities to environmental risks. In the context of siting potentially polluting facilities, complainants can seek prospective relief through the Environmental Protection Agency's administrative complaint process. To prevail, it must be shown that approval of a siting application would subsequently result in adverse, disparate, and unjustified impacts on surrounding community residents. In the case of the

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academics that comparisons of well-being are meaningful, or if so, that such comparisons can actually be carried out (see Elster and Roemer (1991) for a survey of some of the problems of conceptual and empirical indeterminancy). Finally, the meaning and measurement of well-being are not straightforward. For a survey of issues and recent advancements, see Kahneman and Krueger (2006) and Kahneman and Thaler (2006); for a critical discussion of the concept of well-being, see Scanlow (1998).

[68] Rawls (1996), p. 162.

[69] As noted in Kaplow and Shavell (2002), empirical research on legal rules is in its infancy. Unfortunately, site spproval will typically have manifest distributive consequences so that policy recommendations must make distributive judgments. While welfare economics encompass distributive judgments, its use in siting cases is likely to yield highly uncertain conclusions. It can be argued that "rough and ready" assessments will suffice, as Bell (2004) posits in defense of his Rawlsian extension of the difference principle to environmental justice. However, when the political cost of engaging in decision making that does not command consensus is considered, a highly speculative estimate may actually be worse than no estimate at all. See Kaplow and Shavell (2002), p.p. 457-461 for reactions to problems of conceptual and empirical indeterminancy.

Phoenix Metropolitan Area, the available evidence suggests that recent TRI facility siting has resulted in adverse, disparate, but justified environmental impacts on surrounding Hispanic communities. To the extent these findings are representative of siting impacts elsewhere,[70] a comprehensive policy challenge exists: how should siting applications be evaluated when both heightened environmental risks and economic development benefits are likely to be created?

At the heart of this evaluation process are distributional concerns, concerns between white and minority, low and high income, and advantaged and least-advantaged residents in communities impacted by the proposed TRI facility. Unfortunately, commonly advocated notions of fairness are unreliable distributive principles for evaluating site applications, while prescriptions from normative economics fail to provide an implementable principle of distribution. By advocating a non-consequentialist or deontological pursuit of a right, equality, or a distributive principle, notions of fairness fail to provide a systematic connection to the actual well-being of community residents. Pareto-improving decision making would occur only by chance. In contrast, welfarist evaluations of site applications are consequentialist and teleological, based exclusively on the proposed facility's impact on the individual well-being of host community residents. Nevertheless, given the inherent complexity of a facility-siting controversy, immanent problems of conceptual and empirical indeterminancy in welfarist assessments, and the likely irreversibility of approving and subsequently building a TRI facility, advocating the use of normative economic prescriptions to evaluate siting applications is simply untenable.

Fortunately, appeals to notions of fairness or to normative economic prescriptions are unnecessary. A well-established result from positive economic analysis is that voluntary two-party bargaining in a zero-transaction-cost world results in optimality (Coase, 1960). In the context of facility-siting approval, voluntary negotiations between minority community residents and TRI facility applicants could reasonably be expected

[70] Banzhaf and Walsh (2005) in their detailed and site-specific analysis of TRI sites in California, as well as Been and Gupta (1997) in their national and census tract analysis of TSDF sites, report similar findings that suggest benefit/risk tradeoffs may characterize many facility-siting proposals. For a case-study discussion of a siting controversy in Louisiana involving economic development benefits and environmental risk tradeoffs, see Shrader-Frechette (2002) p.p. 74-92.

to result in Pareto-improving decision making if transaction costs can be minimized.[71] Here the regulatory agency is cast in the role of reducing the logistical costs of negotiation and creating bargaining conditions consistent with free informed consent, not in the role of outside analyst. As a result, unlike prescriptions from normative economics, negotiated approaches to siting approval are not overwhelmed by information requirements and empirical indeterminancy. Residents are well-positioned to assess the welfare impacts of environmental risks and economic development benefits, to make appropriate interpersonal comparisons of well-being, and to develop a consensual procedure for aggregating welfare impacts across involved parties. Moreover, unlike notions of fairness, a negotiated approach to siting approval is consequentialist in nature, based on community residents' tastes and preferences. Rights, equality, and distributive principles will be pursued only to the extent that they enter the utility calculations of residents directly, not deontologically. [72]

Several of the concerns raised by notions of fairness are addressed by adopting a negotiated approach to site approval. By making approval contingent upon community endorsement, low-income and minority residents acquire an important property right, the right to be free of any additional environmental risk that the facility might pose. To minimize transaction costs, residents of the host community must be fully informed of both environmental risks and economic development benefits, and be able to fully participate in the negotiation process, necessary conditions for free informed consent and procedural justice. Additionally, by promoting autonomous decision making and self-determination, community residents are free to select a mix of primary goods that are welfare enhancing, based on their own perceptions and judgments.

[71] Several states have adopted negotiated approaches to the evaluation of siting applications. For a survey of current environmental justice programs visit http://www.abanet.org/irr/committee/environmental/statestudy.pdf. Last accessed 7/2006.

[72] The justification presented here for negotiated approaches to evaluating TRI facility-siting applications is that it offers a conceptually coherent and empirically tractable principle of distribution that does not rely on notions of fairness or normative economic prescriptions. In the special case of a negotiated evaluation resulting in both application approval and community compensation, Been (1994) argues that it is desirable to compensate impacted communities when siting benefits are regional, and that firms would have an additional incentive to make siting decisions judiciously.

Clearly formidable procedural challenges remain, challenges involving the scope of, consent to, involvement in, and enforcement of negotiated agreements.[73] While each of these concerns has significant implications for procedural justice, none are empirically intractable. Adopting a Coasian approach to conflict resolution and substantive justice provides a conceptually coherent framework for decision making that is welfare enhancing and Pareto consistent.

[73] For an introductory discussion of the scope of feasible and permissible items for negotiation, see Been (1994). For an evaluation of the need for and requirements of free informed consent, see Faden and Beauchamp (1994). For a survey of the challenges posed by promoting broad public participation in the process of reaching a negotiated accord, see Foreman (1998), p.p. 34-63. Finally, for a discussion of procedural justice considerations in a case-study setting, see Shrader-Frechette (2002), p.p. 71-93.

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Appendix: Simultaneous Equation Estimation

The simultaneous model used for explaining siting decision and reverse causality is given by:

(1) $$EXPOSURE^*_{it} = b_0 + b_{00} \cdot DUM2000_{it} + b_1 \cdot MANUFCTG_{it} + b_2 \cdot INCOME_{it} + b_3 \cdot RENT_{it} + \gamma_1 \cdot SHMIN_{it} + u_{1it}$$

$$EXPOSURE_{it} = \begin{cases} 0 \text{ if } EXPOSURE^*_{it} \leq 0 \\ 1 \text{ if } EXPOSURE^*_{it} > 0 \end{cases}$$

and

(2),

$$SHMIN_{it}=c_0+c_{00}\cdot DUM2000_{it}+c_1\cdot OWN_{it}+c_2\cdot DENSITY_{it}+\gamma_2\cdot EXPOSURE_{it}^*+u_{2it},$$

where, $b_0, b_{00}, b_1, b_2, b_3, c_0, c_{00}, c_1, c_2, \gamma_1, \gamma_2$ are parameters to be estimated, u_{1it} and u_{2it} are disturbance terms, *DUM2000* is a dummy variable for year 2000 and other variables are as given in Table 1. The structural model given in equations (1) and (2) is simultaneous with unobservable endogenous variable on the right hand side of (2). An estimation procedure should account for this simultaneity and possible correlation between u_1 and u_2 to obtain consistent and efficient parameter estimates. Traditional instrumental methods are not feasible because of the unobservable nature of the endogenous variable on the right hand side of (2)[74]. We derive the reduced form model from the structural model and estimate it with full information maximum likelihood methods.

We assume that error terms in equations (1) and (2) are jointly normally distributed as:

(3) $$\begin{pmatrix} u_{1it} \\ u_{2it} \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{pmatrix}\right].$$

As is customary in probit models, the variance of u_1 has been normalized to 1. The structural model given in equations (1) and (2) can be written in its reduced form as:

[74] A simultaneous model with observed binary variable, *EXPOSURE*, instead of unobservable *EXPOSURE**, on the right hand side of (2) is internally inconsistent and cannot be estimated unless $\gamma_1 = 0$ or $\gamma_2 = 0$. See Maddala, pages 117-118.

(4) $y_{1it}^{*} = \left(xb_{1it} + \gamma_1 \cdot xb_{2it}\right) / \left(1 - \gamma_1 \cdot \gamma_2\right) + \varepsilon_{1it} = rhs_{1it} + \varepsilon_{1it}$

(5) $y_{2it} = \left(xb_{2it} + \gamma_2 \cdot xb_{1it}\right) / \left(1 - \gamma_1 \cdot \gamma_2\right) + \varepsilon_{2it} = rhs_{2it} + \varepsilon_{2it}$

where, y_{1it}^{*} is $EXPOSURE_{it}^{*}$, y_{2it} is $SHMIN_{it}$,

$xb_{1it} = b_0 + b_{00} \cdot DUM2000_{it} + b_1 \cdot MANUFCTG_{it} + b_2 \cdot INCOME_{it} + b_3 \cdot RENT_{it}$

$Xb_{2it}=c_0+c_{00}\cdot DUM2000_{it}+c_1\cdot OWN_{it}+c_2\cdot DENSITY_{it}$,

$\varepsilon_{1it} = (u_{1it} + \gamma_1 \cdot u_{2it}) / (1 - \gamma_1 \cdot \gamma_2)$, and

$\varepsilon_{2it} = (\gamma_2 \cdot u_{1it} + u_{2it}) / (1 - \gamma_1 \cdot \gamma_2)$.

Given that u_{1it} and u_{2it} are normally distributed random variables, ε_{1it} and ε_{2it} are also normally distributed. That is,

(6) $\begin{pmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \end{pmatrix} \sim N\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} s_{11} & s_{12} \\ s_{12} & s_{22} \end{pmatrix}\right]$

where, $\begin{bmatrix} s_{11} & s_{12} \\ s_{12} & s_{22} \end{bmatrix} = \begin{bmatrix} \dfrac{1+\gamma_1^2\sigma_{22}+2\gamma_1\sigma_{12}}{\left(1-\gamma_1\gamma_2\right)^2} & \dfrac{\gamma_2+\gamma_1\sigma_{22}+\left(1+\gamma_1\gamma_2\right)\sigma_{12}}{\left(1-\gamma_1\gamma_2\right)^2} \\ \dfrac{\gamma_2+\gamma_1\sigma_{22}+\left(1+\gamma_1\gamma_2\right)\sigma_{12}}{\left(1-\gamma_1\gamma_2\right)^2} & \dfrac{\gamma_2^2+\sigma_{22}+2\gamma_2\sigma_{12}}{\left(1-\gamma_1\gamma_2\right)^2} \end{bmatrix}$.

Note that, the conditional distribution for $\varepsilon_{1it} \mid \varepsilon_{2it}$ is also normal and is given by:

(7) $\varepsilon_{1it} \mid \varepsilon_{2it} \sim N\left[\left(s_{12}/s_{22}\right)\cdot\varepsilon_{2it},\quad s_{11}\cdot\left(1-\rho^2\right)\right]$, where $\rho = \dfrac{s_{12}}{\sqrt{s_{11}\cdot s_{22}}}$ is the correlation coefficient.

Because pooled data from two different time periods (1990 and 2000) are used for estimation of model parameters, error terms are allowed to exhibit time-wise heteroscedasticity. Time varying heteroscedasticity is accommodated by rewriting the variances and covariances as:

(8a) $\sigma_{12it} = \sigma_{12a} + \sigma_{12b} DUM2000_{it}$

(8b) $\sigma_{22it} = \sigma_{22a} + \sigma_{22b} DUM2000_{it}$

Under the formulation in (8a) and (8b), a test for heteroscedasticity is conducted by simply testing the hypothesis, $\sigma_{12b} = \sigma_{22b} = 0$. Obviously, when error terms *u*'s are heterscedastic, error terms ε's, being linear functions of u's, are also heteroscedastic. In particular, s_{11}, s_{12}, s_{22} and ρ are also time varying when heteroscedasticity is allowed.

Full information maximum likelihood estimates of the parameters $(b_0, b_{00}, b_1, b_2, b_3, c_0, c_{00}, c_1, c_2, \gamma_1, \gamma_2, \sigma_{12a}, \sigma_{12b}, \sigma_{22a}, \sigma_{22b})$ are obtained by maximizing the following log-likelihood function:

$$(9)\ \ln L = \sum_{it \in (y_{1it}=1)} \ln prob\left(y_{1it}=1 \mid y_{2it}\right) + \sum_{it \in (y_{1it}=0)} \ln prob\left(y_{1it}=0 \mid y_{2it}\right) + \sum_{t=1}^{2}\sum_{i=1}^{n} \ln f\left(y_{2it}\right)$$

where, $f\left(y_{2it}\right) = f\left(\varepsilon_{2it} - rhs_{2it}\right)$ is a marginal distribution. The conditional probabilities in (9) can be evaluated using results in (7).

$$\begin{aligned} prob\left(y_{1it}=1 \mid y_{2it}\right) &= prob\left(y_{1it}^{*} > 0 \mid y_{2it}\right) \\ &= prob\left(\varepsilon_{1it} > -rhs_{1it} \mid y_{2it}\right) \end{aligned}$$

Conditioning on y_{2it} is equivalent to conditioning on ε_{2it} because, given exogenous variables and y_{2it}, ε_{2it} can be obtained using (5). Hence, the conditional probability can be written as,

$$\begin{aligned} prob\left(\varepsilon_{1it} > -rhs_{1it} \mid y_{2i}\right) &= prob\left(\varepsilon_{1it} > -rhs_{1it} \mid \varepsilon_{2it}\right) \\ &= prob\left(\varepsilon_{1it} < rhs_{1it} \mid \varepsilon_{2it}\right) \end{aligned}$$

Subtracting the mean and dividing by the variance of the conditional distribution from both sides of the above inequality, we get

$$\begin{aligned} prob\left(\varepsilon_{1it} < rhs_{1it} \mid \varepsilon_{2it}\right) &= prob\left(\frac{\varepsilon_{1it} - \left(s_{12}/s_{22}\right)\cdot \varepsilon_{2it}}{\sqrt{s_{11}\cdot\left(1-\rho^2\right)}} < \frac{rhs_{1it} - \left(s_{12}/s_{22}\right)\cdot \varepsilon_{2it}}{\sqrt{s_{11}\cdot\left(1-\rho^2\right)}} \mid \varepsilon_{2it}\right) \\ &= prob\left(z < \frac{rhs_{1it} - \left(s_{12}/s_{22}\right)\cdot \varepsilon_{2it}}{\sqrt{s_{11}\cdot\left(1-\rho^2\right)}} \mid \varepsilon_{2it}\right) \\ &= \Phi\left(\frac{rhs_{1it} - \left(s_{12}/s_{22}\right)\cdot \varepsilon_{2it}}{\sqrt{s_{11}\cdot\left(1-\rho^2\right)}}\right) \end{aligned}$$

$$= \Phi\left(\frac{rhs_{1it} - (s_{12}/s_{22}) \cdot (y_{2it} - rhs_{2it})}{\sqrt{s_{11} \cdot (1-\rho^2)}} \right)$$

where Φ is the cumulative standard normal distribution. The second conditional probability in (9) can be evaluated in a similar way.

$$\begin{aligned} prob(y_{1it} = 0 \mid y_{2it}) &= prob(y_{1it}^* < 0 \mid y_{2it}) \\ &= prob(\varepsilon_{1it} < -rhs_{1it} \mid y_{2it}) \\ &= prob(\varepsilon_{1it} < -rhs_{1it} \mid \varepsilon_{2it}) \\ &= \Phi\left(\frac{-rhs_{1it} - (s_{12}/s_{22}) \cdot (y_{2it} - rhs_{2it})}{\sqrt{s_{11} \cdot (1-\rho^2)}} \right) \end{aligned}$$

Using the expressions derived for conditional probabilities, the log-likelihood function in (9) can now be written in its final form as:

$$\begin{aligned} (10)\quad \ln L &= \sum_{t=1}^{2} \sum_{i=1}^{n} y_{1it} \cdot \ln \Phi\left(\frac{rhs_{1it} - (s_{12it}/s_{22it}) \cdot (y_{2it} - rhs_{2it})}{\sqrt{s_{11it} \cdot (1-\rho_{it}^2)}} \right) \\ &+ \sum_{t=1}^{2} \sum_{i=1}^{n} (1 - y_{1it}) \cdot \ln \Phi\left(\frac{-rhs_{1it} - (s_{12it}/s_{22it}) \cdot (y_{2it} - rhs_{2it})}{\sqrt{s_{11it} \cdot (1-\rho_{it}^2)}} \right) \\ &- \sum_{t=1}^{2} \sum_{i=1}^{n} 0.5 \ln s_{22it} - 0.5 \sum_{t=1}^{2} \sum_{i=1}^{n} (y_{2it} - rhs_{2it})^2 / s_{22it} \end{aligned}$$