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A national inventory and analysis of US transfer of development rights programs

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Transfer of development rights (TDR) programs shift development intensity between land parcels. Jurisdictions, most commonly local municipal or county governments, employ TDR to protect resources such as farmland or historical properties and to encourage infill and redevelopment where deemed appropriate. However, while championed by economists and others seeking to reduce conflicts between land development and preservation, TDR program adoption has varied widely across the US. What demographic, economic, or environmental factors are associated with TDR program establishment? This paper describes a census of 375 TDR programs in the United States, documenting primary program attributes and adoption year and categorizing their functions and typology. Using logistic regression, we analyze program spatial patterns and factors predicting program implementation. We find that areas that are coastal, more liberal, have higher home values, in home-rule states, and in states with state-wide growth management programs, are all significantly more likely to implement TDR programs.

Keywords: transfer of development rights; density transfer; market-based incentives; land use policy; urban density; flexible zoning

1. Introduction

Over the last few decades, urban planners have developed a number of strategies that leverage markets to achieve planning goals, and transfer of development rights (TDR) programs are a prime example (Wright and Czerniak 2000). Local governments create and administer TDR programs to supplement conventional zoning and growth management practices. TDR programs are land use management tools that allow property owners to buy and sell development rights in order to better align development patterns with planning priorities (McConnell and Walls 2009; Nelson, Pruetz, and Woodruff 2011).

Specifically, TDR programs offer a means of compensation to property owners in return for the permanent preservation of ecological, agricultural, or cultural resources on their properties. In doing so, TDR programs can help to align landowner incentives with municipal policy, increasing development opportunities in some areas, while preserving land or other natural resources elsewhere (Nelson, Pruetz, and Woodruff 2011). TDR programs can thus, in theory, smooth what would otherwise be a politically difficult process.

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Although TDR programs have become more commonplace over the last two decades, TDR program implementation and success has been uneven around the country, with wide variation in the number of trades and amount of land preserved under adopted programs (Nelson, Pruetz, and Woodruff 2011; Linkous and Chapin 2014). Some localities have seen very little or no trading, while other TDR programs have enabled significant land conservation and infill development.

This study seeks to understand why, and for what purposes, TDR programs are adopted by investigating an array of local demographic and environmental characteristics. We begin by reviewing research on TDR programs before laying out our methodology, findings, and discussion.

2. Understanding transfer of development rights

2.1. TDR program mechanics

TDR programs have taken many forms given the variety of different planning priorities that exist across US localities. Conventional TDR programs enable the movement of development rights from so-called 'sending sites' in rural or urban preservation areas to 'receiving sites' in areas capable of handling new development (Nelson, Pruetz, and Woodruff 2011). Historically, such transfers are from rural areas to already urbanized areas, though some programs focus on historic preservation goals through urban-to-urban transfers, others on rural development goals through rural-to-rural transfers, and yet others on different goals and types of transfers (Linkous and Chapin 2014; Linkous 2016). Local governments can thus design TDR programs to facilitate their own planning goals, whether these are economic development, resource conservation, or historic preservation.

Transfer of development rights programs are possible because in the United States, as in other countries that have inherited British common law traditions, the ownership of land involves a bundle of rights, including the rights to sell, lease and develop property (Nelson, Pruetz, and Woodruff 2011). TDR programs operate by allowing property owners to sell or purchase some or all of the development rights associated with land ownership. A property owner who sells development rights retains the right to buy, sell, or lease their property, along with other rights; however, a permanent conservation easement runs with the land from which development rights are sold, meaning the owner no longer possesses the right to develop the land in accordance with the property's zoning classification (Machemer and Kaplowitz 2000). A property owner who has purchased development rights and applied them to a parcel they own in a receiving area adds to the existing development potential of their land in accordance with any development bonuses allowed under the local government's TDR program.

The redistribution of development rights enabled by TDR not only serves to manage the fiscal windfall/wipeout effects of land regulation, it is also used to address property rights concerns. TDR can be seen as providing an economically viable use for property impacted by land use regulations, thus mitigating the local government's liability for a regulatory taking (Linkous 2016). This is especially relevant where local governments seek to reduce development potential, such as the downzoning of rural lands or the limiting of development on historic properties. Although the viability of TDR in addressing the US Constitution's Fifth Amendment's "takings" prohibition (i.e. public confiscation of private property without compensation) is not fully established by case law, and depends to some degree on the existence of a market for

development rights that ensures economic viability, TDR is nevertheless seen as a practical and political tool for balancing planning and property rights interests, and is used in states like Florida, where strong property rights protections are in place (Linkous 2016).

Conventionally, a TDR program designates sending areas from which property owners can sell development rights, receiving areas to which development rights may be transferred, and the procedures through which these activities take place. Local planning activities might designate agricultural land, environmentally-sensitive lands, historic properties, rural conservation and open space areas, or other areas where limited development is desired, to be sending areas (Nelson, Pruetz, and Woodruff 2011). Plans may designate urban-designated areas, redevelopment zones, or other areas identified for growth as receiving areas, and specify the amount of bonus density that these areas can receive in terms of additional housing units, density, or floor area (Nelson, Pruetz, and Woodruff 2011). New York City, for example, has set up a number of TDR 'special districts' that designate where and how many development rights can be transferred in order to encourage an urban form consistent with the purposes of each district (Been and Infranca 2012).

Sending areas and receiving areas can overlap with existing zoning districts or be new districts mapped by the TDR ordinance (Nelson, Pruetz, and Woodruff 2011). Their boundaries depend upon the extent of areas targeted for conservation and on areas deemed appropriate for densification (Machemer and Kaplowitz 2000). For example, a TDR program aimed at conserving highly productive agricultural land and stimulating investment in existing urbanized areas may designate a rural sending area that encompasses the productive agricultural land and a downtown receiving area. A program aimed at historic conservation and stimulating high-density redevelopment may only allow transfers within a single urban district. TDR programs can also use additional restrictions regarding the spatial relationship of sending and receiving parcels; for example, some programs require that parcels must be adjacent or under the same ownership, in order to limit the amount of density that can accumulate in any one area (Machemer and Kaplowitz 2000).

Linkous and Chapin (2014) sorted TDR programs into three broad categories:

1. *Conventional TDR programs* transfer development potential from rural to urban areas, focusing on preserving agricultural and environmentally sensitive land, including wetlands, slopes, forests, natural viewsheds, animal habitats, and open space. Their focus is more on *preserving* sending areas than on developing the receiving areas.
2. *Hybrid TDR programs* transfer development potential from rural to urban or fringe locations. Although these programs incorporate preservation goals, hybrid TDR programs place a strong emphasis on incentivizing *development* because they designate receiving areas in fringe locations where there is heightened demand for, or fewer barriers to, new development. These programs typically promote smart and compact growth patterns, often through new town or village development forms.
3. *Rural TDR programs* are designed to shift development between a rural sending area and a rural receiving area. These programs create a mix of compact communities and conserved lands with a goal of accommodating growth while permanently protecting resource lands.

2.2. *The promise of TDR programs*

TDR programs have been lauded for offering numerous advantages over conventional zoning and other conservation tools. First, TDR differs from the more conventional conservation tool of purchase of development rights (PDR) in that TDR involves a transfer, rather than a permanent retirement, of development rights. The retirement of development rights can be costly for local governments and dependent upon the availability of grants and tax revenues (Kaplowitz, Machemer, and Pruetz 2008). Concurrently, the profit motives driving development rights transfers, which are initiated by private landowners and developers (Kaplowitz, Machemer, and Pruetz 2008), function as a powerful incentive for participation in TDR markets. TDR programs also complement growth management strategies by enabling both conservation and development intensification in areas that local plans determine to be appropriate for these activities. While these goals can be accomplished through conventional rezonings, TDR programs reduce the controversial nature of rezonings that produce 'wipe-outs' in lost property value for owners of down-zoned parcels and 'windfalls' for owners of up-zoned parcels (see Hagman and Misczynski 1978). In summary, TDR programs are voluntary, driven by private funds, and allow less politicized and more permanent conservation and development alternatives than conventional zoning (Machemer and Kaplowitz 2000).

TDR programs can also lead to a more efficient allocation of development rights. Levinson (1997), for example, pointed out that not all property owners had the intent or ability to develop their properties to the maximum allowed height, while some property owners would inevitably prefer to exceed the maximum allowed height. Therefore, a TDR program setting could, in theory, lead to an allocation of development rights in line with property owners' intentions, while not creating densities exceeding those of a full build-out scenario with a conventional height limit.

2.2.1. *Evaluations of American TDR programs*

Literature evaluating the successes and shortcomings of TDR programs is extensive and has grown over time as more localities have adopted new programs. Foremost, studies note that while TDR programs resemble other market-based approaches to natural resource conservation, such as pollution trading (Dales 1968; Boyd *et al*. 2003), the potential of TDR relative to similar programs is limited for at least three reasons, according to one Brookings Institution study (Fulton *et al*. 2004). The first has to do with the unique nature of land development as a relatively permanent decision, meaning that development rights cannot be transferred back to their source, unlike with pollution credits. Second, because such decisions are voluntary and essentially happen once for any given property, it is difficult to predict when a TDR program will begin to fulfill its goals. Thirdly, land markets feature a relatively small number of buyers and sellers (Fulton *et al*. 2004). In short, a vibrant market for development rights transfers is very difficult to create.

Nelson, Pruetz, and Woodruff (2011) compiled the most comprehensive study of TDR programs in the United States, surveying 3,500 communities. Their survey revealed that there were only 239 programs, most of which were principally concerned with conservation of natural, agricultural, or historic resources; downtown development, urban design, housing and other development-oriented programs were a small minority.

There is mounting evidence pointing to numerous barriers to TDR program success, which may also create hurdles for initial program adoption. Some studies have

found certain local characteristics that make for a successful program, and these characteristics are hardly universal. Pruetz and Standridge (2008) analyzed the 20 most successful programs across the US (measured as total area of land preserved), finding that all of these programs existed in jurisdictions with significant demand for development that had carefully chosen receiving areas based upon factors such as the availability of existing infrastructure and minimal opposition to new development. Other factors, such as strict regulations for sending areas and support for rural preservation were also shared by a majority of these highly successful programs.

One recent study (Linkous and Chapin 2014) found a number of challenges for TDR programs that may well deter many jurisdictions from seeing TDR as a good strategy for achieving growth management goals. The study found that the state's first generation of conventional rural-to-urban TDR programs – from the 1970s – were largely inactive because they were inadequately linked to market conditions and thus failed to facilitate many transfers. More recent programs that designated receiving areas on the urbanizing fringes of cities, or in rural areas, were more effective in conserving thousands of acres of rural land but at the cost of encouraging increased sprawl in greenfield areas. Private and public actors also face a variety of transaction costs in managing TDR programs, involving research, negotiations, contracts, and administration (Shahab, Clinch, and O'Neill 2018, 2019).

Thus, despite the various theoretical advantages of TDR programs, a variety of challenges prevent widespread program adoption. Furthermore, not all localities that have adopted TDR programs possess the characteristics necessary for successful implementation. This leads to the question of the type of jurisdictions that do adopt TDR programs; although a deep body of research investigates the reasons for local government adoption of related planning strategies, little research specifically investigates the adoption rationale for TDR. Linkous, Laurian, and Neely (2019) tackle this question, drawing on the literature assessing reasons for local government adoption of growth management, sustainability, and market-based planning tools to identify variables that may predict adoption of TDR; their framework identifies geographic, sociodemographic, economic, political, governmental, planning capacity, and interdependent factors. Based on a study of Florida county TDR programs, they found that jurisdictions adopting TDR programs tended to be larger in geographic size, have higher agricultural product sales, home rule authority, a greater proportion of Republican voters, as well as voter-supported conservation ballot measures, leading the authors to suggest that market-based planning mechanisms such as TDR were more popular among political conservatives.

Similarly, in this paper, we seek to address the question: what demographic, economic, or environmental factors are associated with TDR program establishment? However, we address this question at the national scale, assessing the range of operating TDR programs across the US and the types of communities that adopt them.

2.2.2. Data

To census all US TDR programs (active and, to the extent possible, inactive), we drew on two primary sources of data: (1) prior efforts in the literature to document TDR programs, and (2) local government code and ordinance databases.

2.3. Prior efforts to document TDR programs

We began by following up on the 239 programs originally identified in the comprehensive text on TDR program development and applications by Nelson, Pruetz, and Woodruff (2011), *The TDR Handbook: Designing and Implementing Transfer of Development Rights Programs*. This database – which was built on earlier work by Pruetz (1997, 2003) – also documented information on methods of implementation and program function. We also drew on work by Linkous and Chapin (2014), who catalogued 31 county-scale TDR programs in Florida and created a typology describing how programs evolved to meet different conservation and development objectives (described below). Finally, we obtained data from Pruetz's (2019) *Smart Preservation* website, which contains an updated list of 257 TDR programs, as well as program descriptions. We agglomerated and updated each of these databases, checking the current (2019) status of each of these programs through direct contact with local government staff.

2.4. Municipal code database search

Second, we collected data from the five leading web hosting services for municipal and county code and ordinance documents, including Municode (2019), Quality Code Publishing (2020; "Qcode"), Sterling Codifiers (2020), Code Publishing (2020), and American Legal Publishing (2020). Together, these publishers include more than 7,000 municipal and county codes across the United States, spanning communities with a wide range of geographies and jurisdictional sizes and capacities. The use of code databases is a relatively nascent technique for understanding local government regulatory efforts on a broad scale (e.g. see efforts by Schneider [2019], who studied municipal regulatory responses to bedbug infestations). Mirroring search techniques employed by Linkous and Chapin (2014), we searched all listings (across all available states) for TDR ordinances, include search terms: "TDR," "transferable development rights," transfer of development rights," "density transfer," and "transfer."

Efforts were made to verify the existence and status of all programs. Planning and municipal staff were contacted in all programs a minimum of three times to gather data on the status of programs. Responses were obtained from 85.3% of the programs ($n = 320$), with the remainder still maintained in the database. In cases where discrepancies were found between information from our secondary sources discussed above and the individual TDR ordinances, we relied on the codified ordinance language (as it may have been more recently updated) and discussions with program staff. Programs that exclusively enabled same-site transfers to protect environmental features such as wetlands were not included because these programs are more akin to clustering provisions.

2.5. Database and TDR program typologies

We compiled the characteristics of identified TDR programs, including the jurisdiction and state in which the program was created (including the type of jurisdiction and geographic identification for mapping purposes; each program was assigned a geographic ID that corresponded to respective jurisdictional types of US Census geospatial boundary data, described below), the presence or absence of a state statute that enables or guides TDR ordinances, the program's name, the ordinance or code section that codifies the program, the year of adoption and termination (if applicable), and the type of TDR program. In some cases, we were unable to locate the ordinance section (6

programs) and date of adoption or modification (17 programs). Moreover, data acquisition problems also occurred for programs that had been repealed and removed from codes (and therefore, not included in the regression portion of the analysis in this paper). This limitation could be overcome in future research through additional direct contact with administrators within those jurisdictions, although in some cases local governments did not maintain historical records of program evolution and activity.

We employed the program typology from Linkous and Chapin (2014), who categorize programs by the types of sending and receiving areas established: conventional, hybrid, and rural. However, we add a fourth category of urban to account for programs aimed at intra-urban transfers, an approach Linkous and Chapin's work on county-level TDR programs for growth management did not include. In this category, *Urban TDR programs* focus on redeveloping urban landscapes and are typically designed to preserve historic landmarks and promote redevelopment.

2.6. Mapping and co-variate data

To map TDR programs, we joined program information with geospatial boundary data – specifically, the 2017 US Census TIGER/Line boundaries of county, county subdivision, municipal, and census tract boundaries (US Census Bureau 2017b) – based on programs' Federal Information Processing Standard (FIPS) codes (identifying municipality or county). Four of the five regional programs have unique administrative boundaries; geographic boundary data for New Jersey's Highlands and Pinelands, New York's Central Pine Barrens, and the Tahoe region were acquired from agency websites (New Jersey Highlands Council 2020; Pinelands Commission 2020; TRPA 2020) or agency contacts (Suffolk County Water Authority and Central Pine Barrens Commission 2020). The other regional program, Puget Sound, comprises four participating counties: King, Pierce, Snohomish, and Kitsap.

To understand the demographic, economic, environmental, and governance factors associated with TDR program establishment, we collected a variety of covariate data (Table 1). Selection of explanatory variables was informed by the framework identified by Linkous, Laurian, and Neely (2019), but adapted to the national context based on data availability. For example, we excluded staff planning capacity data since this information is not available for many non-Florida jurisdictions. We also drew on the work of BenDor *et al*. (2021) that identifies variables associated with water quality trading programs, an environmental market that frequently operates at similar scales and in similar locales to TDR programs. Tract-level population, population change, white population, urban population, and occupied housing units, as well as county-level population, land area, and municipal land area, are drawn from US Census Bureau Decennial Census data acquired via Social Explorer (2000, 2010). Similarly, the US Census Bureau's (2017a) American Community Survey 5-year estimates, acquired via Social Explorer, provide tract-level population with a college degree, seasonal vacant homes, home ownership, housing value, and year-built information.

3. Methodology

3.1. Data processing and sampling

TDR programs have non-uniform geographies and vary in the size of the areas they cover, ranging from small townships (e.g. Mount Joy Township, Pennsylvania;

Table 1. Data and data sources.

	Variable	Variable description	Native resolution	Source
Demographics	Tract population (2010, and 2000–2010 % change)	Total population for 2000 and 2010 used to calculate percentage change in population, former adjusted for interpretability (divided by 1000)	Tracts	US Census Bureau, Decennial Census (2000, 2010)
	County population, 2010 (in 1000s)	Total county population for 2010, adjusted for interpretability (divided by 1000)	County	US Census Bureau, Decennial Census (2000, 2010)
	Population density, 2010 (persons/ha)	Calculated as the number of people per hectare (Derived from SLD variables: 2010 population [US Decennial Census] & total land area in acres [US Census, Navteq Water and Oceans])	Data summarized by SLD to tracts	EPA Smart Location Database (SLD; USEPA 2013)
	White population, 2010 (%)	Percentage of the total population that is white	Tracts	US Census Bureau, Decennial Census (2010)
	College graduate, 2017 (%)	Percentage of the population 25 years and over that has a bachelor's degree or higher	Tracts	US Census Bureau, ACS (2017a)
Housing	Occupied housing rate, 2010 (%)	Percentage of total housing units that are occupied	Tracts	US Census Bureau, Decennial Census (2010)
	Vacant homes are seasonal, 2017 (%)	The percentage of vacant homes that are used for seasonal, recreational, or occasional use	Tracts	US Census Bureau, ACS (2017a)
	Home ownership rate, 2017 (%)	Percentage of non-vacant housing units that are owner occupied	Tracts	US Census Bureau, ACS (2017a)
	Median year housing built, 2017	Median year housing was built	Tracts	US Census Bureau, ACS (2017a)
	log (Median housing value, 2017 (in 1000s))	Median value of housing in 1000s (USD), adjusted for interpretability (divided by 1000) and log transformed	Tracts	US Census Bureau, ACS (2017a)
Geography	Tract located in coastal county (binary)	Binary variable indicating whether tract is in a county that shares at least one border with the coast or an estuary	County	NOAA Office of Coastal Management (2018)
	Tract located in municipality (binary)	Binary variable indicating whether the tract is located within an incorporated municipality	Tract	US Census Bureau (2017b) TIGER/ Line Shapefiles

(*Continued*)

Table 1. (*Continued*).

	Variable	Variable description	Native resolution	Source
	Jurisdiction land area (km^2)	If tract is located in municipality, the land area of the municipality; if located outside a municipality, the land area of the county	Municipality / County	US Census Bureau, Decennial Census (2010)
	Tract area that is urban, 2010 (%)	Population living in urbanized area (50,000 or more people) divided by the total tract population	Tract	US Census Bureau, Decennial Census (2010)
Agriculture	Number of farms, 2012 (in 100 s)	Total number of farms, adjusted for interpretability (divided by 100)	County	NASS (2015
	Mean farm size, 2012 (ha)	Average amount of hectares of land in farms	County	NASS (2015)
	Tract area in cropland, 2012 (%)	Percentage of total tract land area used for the production of crops	County	NASS (2015)
	Farmland in CRP, 2012 (%)	Percentage of farmland enrolled in the Conservation Reserve, Wetlands Reserve, Farmable Wetlands, or Conservation Reserve Enhancement Programs	County	NASS (2015)
	Mean value of agricultural products, 2012 (in 1000s)	Average value of agricultural products sold per farm, in 2012 US dollars, divided by 1,000 to improve interpretability.	County	NASS (2015)
Government	Eligible voter turnout, 2016 (%)	Total votes cast in 2016 presidential election, divided by the total voting age population	County	MIT Election Data and Science Lab (2018)
	Mean political ideology	Study estimated average policy preferences of constituencies using multilevel regression with post-stratification (MRP); ideology scores range from −1 (liberal) to 1 (conservative).	County	Tausanovitch and Warshaw (2013)
	State growth management (binary)	Binary variable indicating whether state has a growth management program or legislation	State	Richardson, Gough, and Puentes (2003)
	Dillon's Rule (limited/ full) [two binary variables]	Three-level categorical variable indicating whether state has fully adopted Dillon's Rule (2), adopted it for some types of local government (1), or it is not a Dillon Rule state (0)	State	Richardson, Gough, and Puentes (2003)

Notes: ACS indicates the US Census Bureau's American Community Survey 5-year estimates (2017a). NASS indicates the USDA's National Agricultural Statistics Service (NASS) (2015). "Tracts" indicates US Census tract boundaries (2010).

28.02 mi^2 [72.6 km^2]) to multi-county regions (e.g. Puget Sound, Washington). For our overall unit of analysis, we selected US Census tracts (2010 boundaries), which allow for a wide exploration of explanatory variables without sacrificing demographic and geographic specificity.

All data was summarized to the tract level, using spatial queries from the *sf* package (Pebesma 2018) in the R statistical software (v. 3.6; R Core Team 2019), which was used for all data management and analysis (see Supplementary Material 1 for access to this article's data and analytical code). Most explanatory variables were acquired with a native resolution at the tract-level; data with a native resolution at the state- and county-level were summarized to the tract level using FIPS codes. Location within a municipality was defined by overlaying geospatial Census-designated Place boundaries (subset to only include incorporated municipalities) with tract boundaries; tracts that were covered by a municipality were assigned to that jurisdiction. TDR programs were assigned to tracts using a spatial join query, where only tracts that fall within the boundaries of a program were assigned its attributes. Supplementary Material 2 offers more details on transformations and outlier removal.

In assigning TDR programs to US Census tracts, it was important that we account for statistical bias affecting our standard error estimator, which could alter our analysis as a result of the spatial clustering of contiguous tracts within a program. To do this, we based our analysis on a 10% sample of tracts (stratified by states, each with at least one program; yielding a total of $n = 5{,}874$ tracts), a rate that ensures a low probability that clustered tracts can bias our analysis (i.e., we were unlikely to sample a large number of observations from a single TDR program). For our regression analysis, we also removed repealed programs ($n = 34$ programs), as well as programs in New York City (11 programs), which are relatively unique in their design and adoption, (NYCPlanning 2015) and generally operate in very tightly-defined sections of the City.

3.2. Logistic regression

We used standard, binary logistic regression modeling to test whether there is a significant, predictive relationship between our demographic, economic, and environmental covariates and the existence (binary) of a TDR program in the local government that is home to a given Census tract. We tested the fit of these logistic regressions using the model's accuracy (i.e. count-R^2), accuracy over the "no information rate" (i.e. accuracy over a null model, which is useful when dependent variables are unbalanced; Kuhn 2008), and the receiver operating characteristics (ROC) curve (Fawcett 2006).

The ROC is a graphical curve that displays the true and false positive rates and threshold settings in order to measure the performance of binary classifiers. The area under the ROC curve (AUROC) measures how each classifier compares to a random model in terms of its ability to predict a binary outcome. An AUROC of near 1 indicates a perfect measure of prediction while one near 0 indicates that the model is predicting the opposite result that it should. An AUROC of 0.5 indicates the model cannot separate between the two outcomes. Generally, models that achieve AUROCs over 0.75–0.8 are considered strong predictive models (Fawcett 2006).

4. Results

4.1. TDR program inventory

Our census of TDR programs revealed 375 programs (of which 34 have been repealed), spread widely across 38 US states and Washington, DC (Figure 1), with clustering in Florida (87 programs), California (42), Pennsylvania (37), Washington (29), and New York (26). In terms of scale, these programs primarily operate at the municipal (71.2%) and county (27.5%) levels, along with five regional programs in New Jersey's Pinelands and Highlands, Long Island's Pine Barrens (New York), Washington's Puget Sound, and California's Lake Tahoe Basin (Figure 2a). Among our total database of programs, we identified 67 (17.9%) through our search of municipal code databases (i.e. beyond those identified in Nelson, Pruetz, and Woodruff [2011], Linkous and Chapin [2014], and Pruetz's [2019]; Figure 2b).

The heyday for program establishment was largely during the 20-year period between 1992 and 2011, when 64.5% of all programs were adopted (Figure 2c). This time frame aligns with the planning profession's emphasis on smart growth policy, of which TDR is an emblematic tool (Chapin 2012). In terms of program typology (Figure 2d), *Conventional TDRs* – which focus on preserving agricultural and environmentally sensitive land – are the most prevalent type of program (209), making up 55.7% of all identified programs. The dominance of Conventional TDR speaks to the fact that this is the most longstanding approach to the tool. *Hybrid TDRs* – which place an emphasis on compact development in fringe receiving areas – are the second most frequent program type observed, with 80 identified (21.3%). *Urban TDRs*, which focus on *redeveloping* urban landscapes and shifting unused development potential entirely within an urban area, account for 60 programs (16.0%; all at the municipal scale). *Rural TDRs*, a relatively new form of TDR which seeks to shift development between rural sending and receiving areas to create desirable future development patterns, account for 26 programs (6.9%).

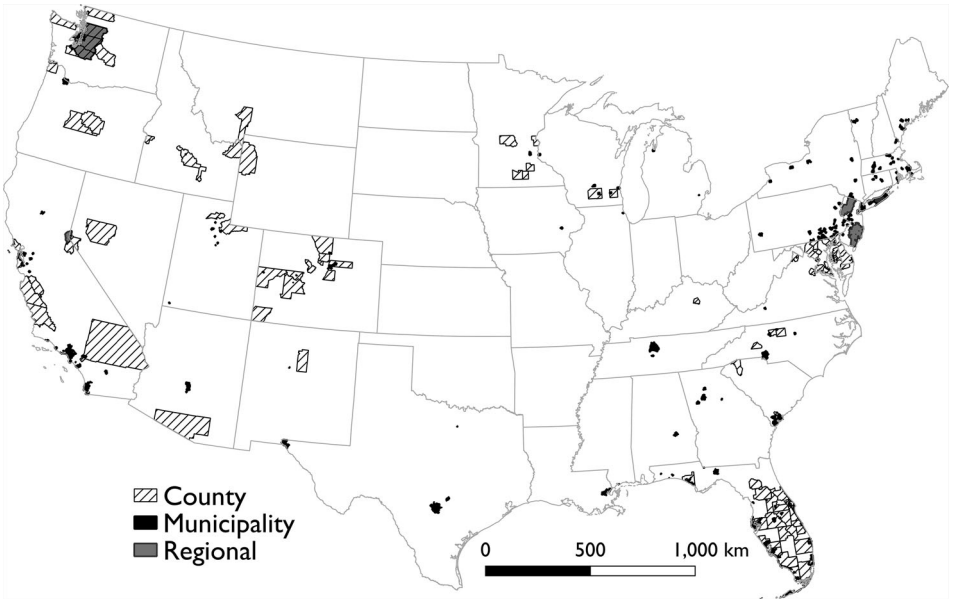

Figure 1. Map of US transfer of development rights (TDR) Programs ($n = 375$).

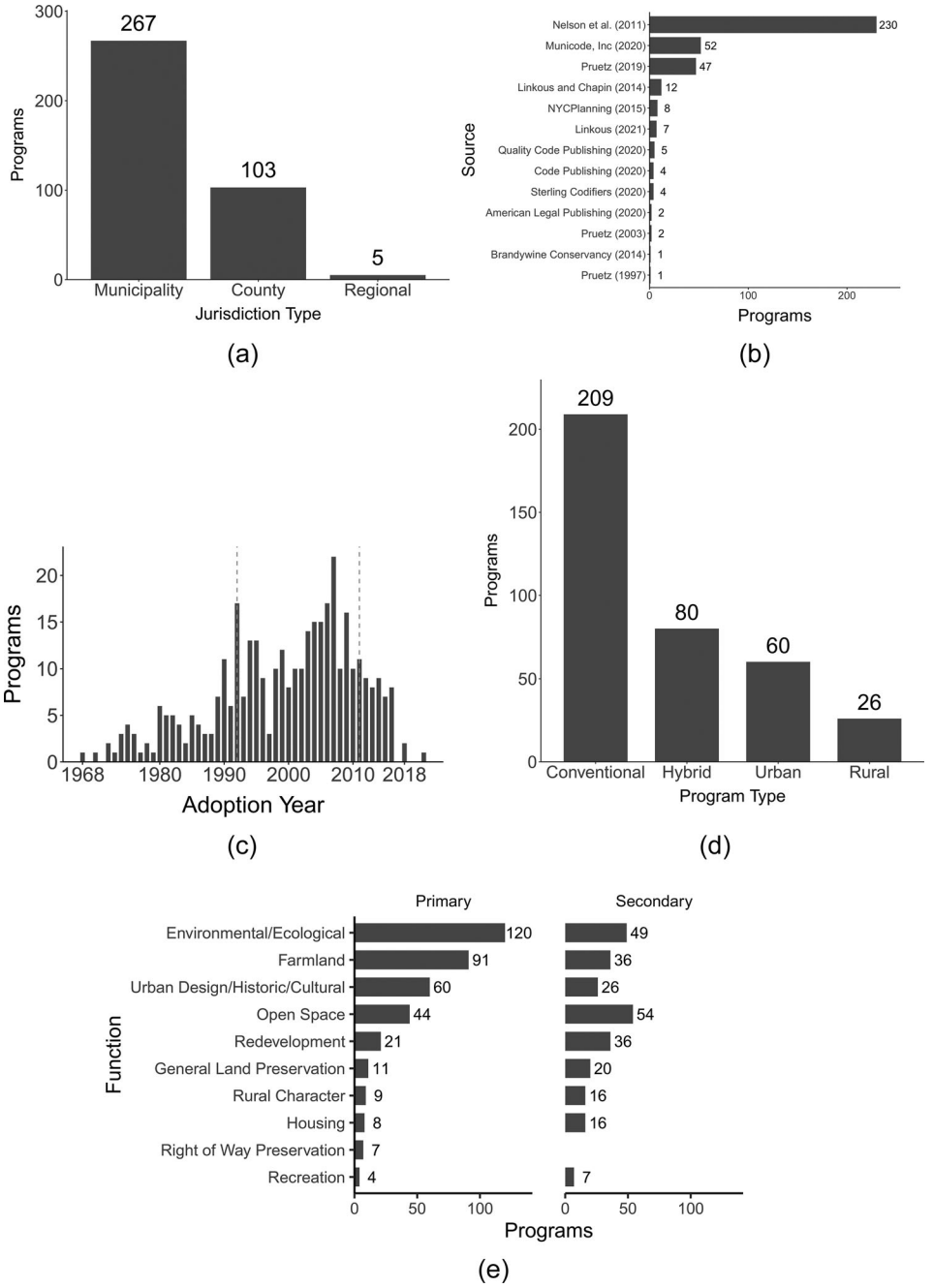

Figure 2. Transfer of development rights (TDR) program jurisdictional types/scales (a), literature and database sources (b), adoption years (c), typologies (d), and primary/secondary functions (e).

Finally, Figure 2e shows the distribution of both primary and secondary program functions (while we only depict the primary and secondary purposes here, our database contains up to six program justifications). While most programs were established with more than one goal in mind, 32.0% of programs highlight environmental/ecological

conservation as their primary purpose, while 24.3% of programs are aimed at farmland preservation. This again relates to the dominance of the original, conventional approach to TDR, which focused on land preservation in rural and environmental areas. Many programs do not have a secondary purpose (30.7%); however, among those that do, open space (20.8%) and environmental/ecological conservation (18.8%) are the most commonly cited.

4.2. *Logistic regressions*

The results of our logistic regression analysis are shown in Figure 3, which depicts the effects (with confidence intervals) of demographic, economic, political, and environmental factors on the odds of a TDR program existing in a given US Census tract ($n = 5{,}540$ tracts, 334 tracts dropped due to the absence of one or more covariates; Table 2 shows the full regression output table.). A collinearity test revealed no problematic linear relationships between the variables (all variance inflation factors [VIFs] < 4; see Supplementary Material 3 and Table S3).

This model has a nuanced fit to the data; the area under the receiver operator characteristic (AUROC) curve is 0.839, indicating a strong fit to the data (Fawcett 2006).

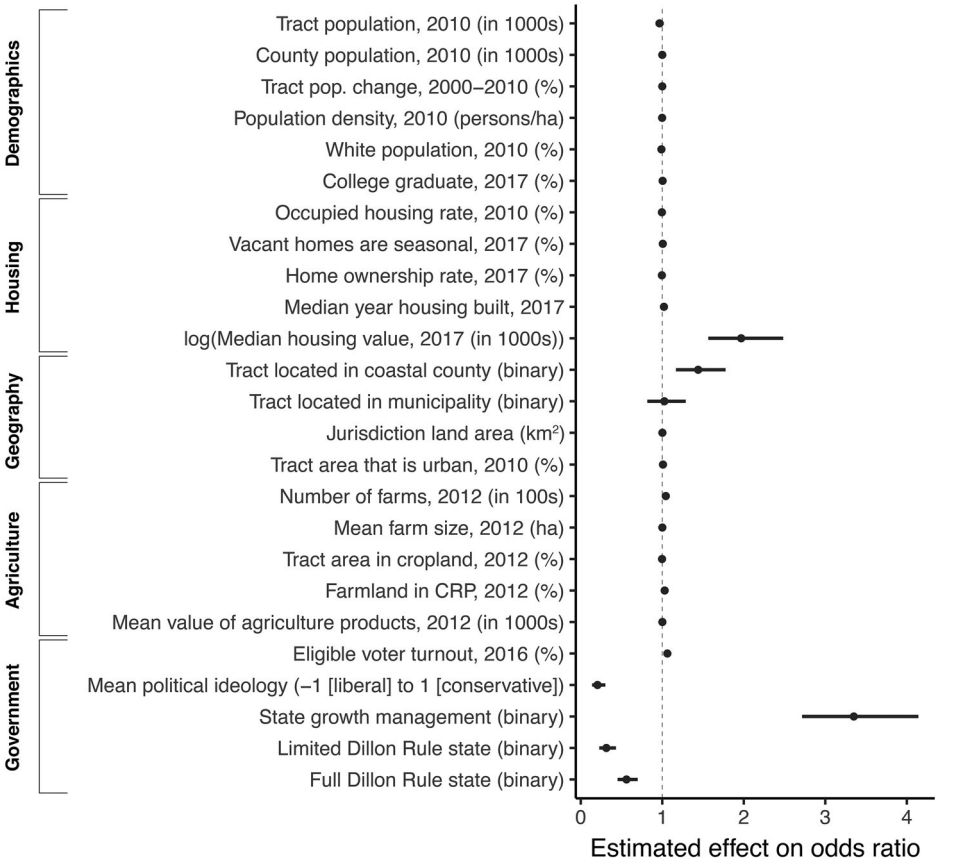

Figure 3. Logistic regression depicting the effects of demographic, economic, and environmental factors on the odds ratios (OR) of transfer of development rights (TDR) program existence. ($n = 5{,}540$ tracts).

Table 2. Full output of logistic regression depicting the effects of demographic, economic, and environmental factors on the odds ratios (OR) of transfer of development rights (TDR) program existence ($n = 5{,}540$ tracts).

		OR [95% interval]
Demographics	Tract population, 2010 (in 1000s)	0.967 [0.917; 1.019]
	County population, 2010 (in 1000s)	1.000 [1.000; 1.000]***
	Tract population change, 2000–2010 (%)	1.000 [0.996; 1.003]
	Population density, 2010 (persons/ha)	0.998 [0.995; 1.001]
	White population, 2010 (%)	0.990 [0.985; 0.994]***
	College graduate, 2017 (%)	1.004 [0.997; 1.012]
Housing	Occupied housing rate, 2010 (%)	0.996 [0.984; 1.007]
	Vacant homes are seasonal, 2017 (%)	1.006 [1.002; 1.010]***
	Home ownership rate, 2017 (%)	0.995 [0.990; 1.000]**
	Median year housing built, 2017	1.020 [1.013; 1.027]***
	log (median housing value, 2017 (in 1000s))	1.963 [1.561; 2.477]***
Geography	Tract located in coastal county (binary)	1.444 [1.171; 1.781]***
	Tract located in municipality (binary)	1.022 [0.814; 1.283]
	Jurisdiction land area (km^2)	1.001 [1.001; 1.002]***
	Tract area that is urban, 2010 (%)	1.009 [1.005; 1.013]***
Agriculture	Number of farms, 2012 (in 100 s)	1.043 [1.035; 1.052]***
	Mean farm size, 2012 (ha)	1.001 [1.000; 1.001]***
	Tract area in cropland, 2012 (%)	0.997 [0.989; 1.005]
	Farmland in CRP, 2012 (%)	1.029 [0.983; 1.075]
	Mean value of agricultural products, 2012 (in 1000s)	1.001 [1.001; 1.002]***
Government	Eligible voter turnout, 2016 (%)	1.062 [1.051; 1.074]***
	Mean political ideology (−1 [liberal] to 1 [conservative])	0.205 [0.139; 0.301]***
	State growth management (binary)	3.356 [2.721; 4.150]***
	Limited Dillon's Rule state (binary)	0.314 [0.227; 0.431]***
	Full Dillon's Rule state (binary)	0.559 [0.449; 0.695]***
	Intercept	0.000 [0.000; 0.000]***
	AUROC	0.840
	Log Likelihood	−1773.317

AUROC indicates the area under the receiver operator characteristic curve.

However, while the model's accuracy (87.3%) significantly exceeds that of a null model (84.6%; $p < 0.001$; proportional t-test), examination of the model's sensitivity (31.9%) and specificity (97.4%) indicates that the model's accuracy varies regarding how well it predicts tracts with and without a TDR program, respectively. We hypothesize that this is largely due to the relatively low proportion of tracts with a TDR program (15.4%; $n = 855$ tracts).

While quite a few of the covariates that we test appear to have statistically significant relationships with TDR program existence, most of these relationships are relatively weak. County population (measured in 1000s), jurisdictional land area, home ownership rate, median year of house construction, and race (percentage white population) all have minute relationships with TDR program adoption, with effects on the TDR odds ratio between 0.99 and 1.02, thereby indicating $a < 2\%$ change based on a unit change in any of these independent covariates.

Our model identifies several variables that are strongly associated with TDR program adoption. First, the presence of the tract in a coastal county (regardless of whether it was in a municipality or not) increases the odds of TDR adoption by

44.4%. Following Linkous, Laurian, and Neely (2019), coastline is used as a measure of valued community environmental attributes, a factor thought to be associated with TDR adoption. Second, we observe a strong, positive relationship between median housing value (measured in 1000s; log transformed) and TDR adoption (OR = 1.968). Although their Florida model did not find a similar relationship, Linkous, Laurian, and Neely (2019) predicted that higher housing values would be associated with TDR adoption due to issues of real estate market demand and potential exclusionary dynamics associated with growth management tools.

Third, our indicator of county-level political ideology (scaled −1 [strongly liberal] to 1 [strongly conservative]; Tausanovitch and Warshaw 2013) is strongly, negatively associated with TDR adoption; a neutral (index = 0) or strongly conservative (index = 1) tract will have 79.5% lower odds of a TDR program than a strongly liberal (index = −1) or neutral (index = 0) county, respectively. As pointed out by Linkous, Laurian, and Neely (2019), market-based instruments are thought to be associated with conservative political ideologies, but growth management and environmental policies are associated with Democratic voters. Our finding suggests that TDR adoption is more politically aligned with liberal contexts.

Finally, we observed strong relationships to state-level growth management and devolution of governance policies; tracts in states with state-wide growth management policies see a 235.0% increase in odds of TDR program adoption. Additionally, tracts in "strong" Dillon's Rule states – those that do not automatically devolve police power to any local governments – see 43.9% lower odds of a TDR program, while tracts in "weak" Dillon's Rule states – those that devolve policy power authority to some local governments – see a 68.6% odds decrease.

5. Discussion and conclusions

Our survey revealed that US county or local governments have, to date, implemented a total of 375 TDR programs, although not all of these remain active. This represents an increase of 63% more programs than Nelson, Pruetz, and Woodruff's (2011) survey revealed a decade ago. However, the total number of programs still represents a small share given the thousands of jurisdictions in the US. In spite of the theoretical benefits of TDR, our research demonstrates that practical application remains limited. This is exacerbated by the apparent decrease in new program adoption since 2007.

The observed slowdown in TDR adoption may relate to the association of TDR with smart growth, a policy framework that is on the ebb given emerging concerns of climate, energy, and social justice as central to contemporary planning. However, TDR's potential relevance to issues of flood zone retreat and shifting littoral property rights perspectives may breathe new life into the tool, as is already evident in places like Miami that are experimenting with new adaptation applications for TDR. The recent decline in adoption of TDR may also be explained by market conditions. Given that a strong market for development is necessary to sustain development rights transfers (Pruetz and Standridge 2008), the appeal of TDR programs may have declined with the 2008 financial crisis. However, some anecdotal evidence from Florida, where three local governments identified TDR transactions in the pipeline after years of program stagnation, points to a resurgence in use of the tool as real estate responds to competitive current market conditions.

We categorized programs according to Linkous and Chapin (2014) typology of conventional, hybrid, and rural programs, also adding urban programs as a fourth category. Our findings show that TDR programs have remained diverse in their aims, as Nelson, Pruetz, and Woodruff (2011) found a decade ago. We also find that programs are most commonly implemented by county and sub-county local governments and are not being widely used as tools for regional growth management. This is also consistent with Nelson, Pruetz, and Woodruff's (2011) findings.

We turn to a discussion of the role of state context in local government TDR adoption. Nearly 59% of TDR programs (operating and repealed) are in just five states: Florida, California, Pennsylvania, Washington, and New York. A state-level factor strongly associated with TDR adoption is the existence of statewide growth management legislation. Of the five states that boast the majority of TDR programs, two (Florida and Washington) have state growth management programs in place (Anthony 2004). Local jurisdictions in states with growth management legislation were nearly three and a half times as likely to adopt TDR programs than those in states without it. This is unsurprising, and likely stems from the enthusiasm and requirements for action on conservation at various levels of government in states with such legislation. Our analysis also revealed that local governments in "strong" Dillon's Rule states – in which local governments cannot pursue TDR without state-enabling legislation or state-specific case law precedents (Nelson, Pruetz, and Woodruff 2011) – have a 43.9% lower chance of adopting TDR. This effect is also present in "weak" Dillon's Rule states. This is consistent with Linkous, Laurian, and Neely (2019) finding that home rule was associated with a higher odds of program adoption in Florida.

The combined findings that TDR adoption is positively associated with state growth management rules and negatively associated with strong Dillon's Rule frameworks suggests that state institutional contexts that encourage or allow use of diverse planning tools foster a more experimental or entrepreneurial local policy environment, one in which innovative tools such as TDR are more likely to be used. Of the five states with the highest number of TDR programs, four (FL, WA, PA, NY) are also among the 25 total US states that have had TDR enabling statutes enacted since 2009 or earlier (Nelson, Pruetz, and Woodruff 2011). However, three of those five (NY, PA, WA) have fully adopted Dillon's Rule for all municipalities ("strong" Dillon's Rule implementation), and CA has a limited ("weak") implementation of Dillon's Rule. Overall, our research does not present clear guidance about the role of state governance in local government adoption of TDR, except to point to an important role for enabling and growth management legislation.

We also found that the presence of tracts in coastal counties is strongly associated with TDR program adoption. Linkous, Laurian, and Neely (2019) used the coastline variable as a proxy for highly-valued environmental amenities, a factor that may vary from place-to-place. The unique contribution of waterfront land – both from an environmental and community quality of life perspective – is well established and presents some possible explanations. Coastal locales are often subject to coastal conservation legislation, which reduces vulnerability and protects a variety of environmentally sensitive ecosystems around shorelines, estuaries, and wetlands (e.g. Onda *et al*. 2020; Parsons 1992). TDR may be used to support local compliance with coastal protection mandates. Concurrently, coastal locales often derive large shares of their economic revenue from conservation-related tourism and recreation (Kubo *et al*. 2020; Guo, Robinson, and Hite 2017), further incentivizing use of planning strategies that protect vital resources.[1]

Linkous, Laurian, and Neely (2019) also hypothesize that coastal areas are also typically more urbanized, and that the increasing sophistication of land management needs and real estate markets in more developed areas may underlie the relationship between coastal communities and TDR. The planning needed to continue to limit development in coastal areas through adaptable tools such as TDR will only increase in an era of growing attention to sea level rise and flood risks.

We next turn to a discussion of the local factors associated with TDR adoption, focusing first on political factors. Our analysis revealed that county-level political orientation plays a large role in determining the odds that local governments implement a TDR program. Under Tausanovitch and Warshaw's (2013) index of county government political ideology, which ranges from most liberal at −1 to most conservative at 1, an increase of 1 (i.e. a strong shift toward county government conservatism) is associated with an 79.5% decrease in the odds of TDR program adoption.

This parallels findings about state growth management programs; while both Republican and Democratic led states have pursued these programs, the first to do so were usually Democratic-leaning states (Anthony 2004). Despite the theoretical appeal of market-based approaches for managing conservation in conservative jurisdictions, it is also notable that previous studies have shown that the adoption and success of TDR programs depend on strong local support for conservation in the first place (Pruetz and Standridge 2008; Linkous, Laurian, and Neely 2019). An enthusiasm gap between relatively more and less conservative areas when it comes to conservation could explain the relative lack of appeal of TDR programs in more conservative areas. These findings do somewhat conflict with those of Linkous, Laurian, and Neely (2019), who found that a higher percentage of Republican voters was associated with program adoption in Florida, a finding they attribute to conservative support for market-based instruments. Our analysis was national in scope, and it may well be the case that the relationship of TDR program adoption to political ideology varies somewhat from state to state. Overall, it appears that the political perceptions and palatability around TDR align more closely with liberal growth management regimes rather than conservative, market centric contexts.

Finally, we turn to a discussion of the role of local development conditions in TDR adoption. Unsurprisingly, we discovered a strong positive relationship between home values and TDR program adoption. TDR relies on a strong real estate market, which creates developer demand for transferred rights that allow for more development, and incentives sending area landowners to participate by elevating prices through increased demand. However, similar to Linkous, Laurian, and Neely (2019), we also found no significant relationships between TDR adoption and local population and population growth rates, lending support to their conclusion that TDR is not used in response to growth pressure.

The evidence here suggests that growth may not be a sufficient rationale for TDR program adoption, which appears to, instead, be informed more by the supply and demand dynamics associated with higher housing values. This nuanced relationship of TDR to growth and development dynamics merits additional inquiry.

Overall, our results point to political support for growth management, unique environmental attributes such as coastal proximity, and the development-driven factor of higher-value real estate values as major drivers of markets for development right transfers. TDR may be best understood as just one more strategy that local governments employ in states and regions that are already supportive of conservation and that are equipped with the legal context and market conditions that support private sector interest in development rights sales.

6. Implications for future research

The analysis conducted in this project suggests future opportunities for additional work, particularly geared toward better understanding the propensity of jurisdictions to adopt programs with specific aims (e.g. urban TDR programs vs. traditional TDR programs, or historic preservation vs. managed retreat). Multinomial logistic regression techniques could be used to better understand whether program type or goals strongly affect program adoption tendencies. Questions about the political and governance context associated with TDR remain. We also see value in research that can explain the relationship between TDR and higher home values, but the lack of relationship to population growth. If this relationship is causal, it could indicate that TDR programs, like other tools of land use regulation and growth management (Fischel 2005), can have exclusionary and inequitable effects.

While our dataset has facilitated a broad analysis of TDR program existence, it does not enable us to delve into the specifics of program operations or success once implemented. Future research could use this database as a starting point for examining the extent of transfers taking place, the amount and nature of land preserved, and the development outcomes associated with TDR transactions.

Finally, our research revealed a need for improved local data collection and tracking of TDR program evolution and transaction activity. Local governments with older programs often indicated limited institutional knowledge of program adoption dates or changes to TDR policies over time. TDR transactions are often not tracked at all by local governments, and those that do track activity do so through a variety of approaches including lists, tabular data, resolutions, deeds, and permits. Several of these approaches to documenting TDR transactions present inconsistent or limited data. For example, the linkages between sending area credits and receiving area credits are often not identified, the prices of credits are often not documented because they occur through private party transactions, and very few programs tag data with geospatial information. These data deficiencies limit the richness of potential research on the tool, but present opportunities by which practitioners and academics can identify process improvements and data collection best practices to create more viable TDR programs moving forward.

Note

1. Interestingly, our model found only a very weak relationship between TDR adoption and higher-value agricultural production, another potential indicator of community values around natural resources.

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Supplemental data

All data and code for the article can be accessed online through the UNC Dataverse, https://doi.org/10.15139/S3/8C1KYA

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