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ABSTRACT

Family-Centered Measures of Access to Early Care and Education*

This study proposes new family-centered measures of access to early care and education (ECE) services with respect to quantity, cost, and quality and uses them to assess disparities in access across locations and socio-demographic groups in Minnesota. These measures are distance-based and use available geographic data to account for the fact that families can cross arbitrary administrative boundaries, such as census tract or ZIP code lines, and thus better reflect the real experiences of families than conventional area-based measures. Combining synthetic family locations simulated from Census demographic and geographic data and information on ECE provider locations, we calculate travel time between the locations of families with young children and ECE providers to measure families' access to providers of different types. The results yield a map of areas with low and high relative ECE access. The average family in Minnesota lives in a location where there are nearly two children for every nearby slot of licensed capacity, however, access to ECE supply varies considerably at the local level. The supply measure can also serve as a weight useful in computing family-centered measures of ECE quality and access costs, incorporating both prices and travel costs, to further characterize the local ECE market from the perspective of families. Improving measures of variation in families' access to ECE quantity, cost, and quality is valuable as policymakers consider expansions to public supports for early learning and ECE entrepreneurs decide where to invest.

JEL Classification: J13, R12, R53, H4, L84

Keywords: child care, spatial analysis, public facility location, services

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Introduction

Access to affordable, high-quality early care and education (ECE) is important because of the dual role of ECE in facilitating employment of parents and in supporting child development. As our understanding of the importance of early childhood learning environments expands, disparities in access to high-quality ECE have become of increasing concern to policymakers. The reauthorization of the Child Care and Development Block Grant (CCDBG) in 2014 established new requirements for states to improve access to high quality ECE ("Child Care and Development Block Grant Act (CCDBG) of 2014," n.d.). Studies that examine community-level measures of the availability of ECE conclude that disparities in access are related to the sociodemographic and economic characteristics of local communities (Bassok, Fitzpatrick, & Loeb, 2011; Bassok & Galdo, 2016; Fischer, Nelson, Mikelbank, & Coulton, 2008; Fuller & Liang, 1996; Gordon & Chase-Lansdale, 2001; Loeb, Fuller, Kagan, & Carrol, 2004).

To ensure adequate access to early care and education, particularly for low-income families, policymakers and planners need accurate measures of access in order to target resources to locations with greatest need. After a comprehensive review of the literature, Friesen, Lin, Forry, & Tout (2017) write, "Recent federal policy changes have placed new requirements on states to demonstrate and document their efforts to improve access to high-quality early care and education (ECE), and have made clear the urgent need for a shared understanding of this concept." Many factors influence families' access to ECE services. Past studies of access have mostly relied on area-based measures of the availability of ECE options. They typically partition a region into non-overlapping zones, using ZIP code, county, census tract, or municipal boundaries. It is common to compare a measure of supply, such as the number of providers, provider capacity, or a count of child care workers, to the number of children within each area (Bassok et al., 2011; Casper & O'Connell, 1998; Cochi Ficano, 2006; Fischer et al., 2008; Fuller & Liang, 1996; Gordon & Chase-Lansdale, 2001; Jacobson, 2001; Neidell & Waldfogel, 2009; Yamauchi, 2010). By defining relevant areas based on administrative boundaries, these conventional measures ignore families' ability to travel across boundaries to find care. They implicitly consider all supply in the same area as a family as equally accessible to that family and all supply outside the area as equally inaccessible. In addition, standard area-based measures treat all families in the area as equally likely to demand all in-area supply and all families outside the area as irrelevant, when in reality, families will cross area administrative boundaries to find care.

This paper builds on the prior literature by developing a new set of family-centered, distance-based measures of access to ECE services' quantity, cost, and quality. We focus on the quantity of supply provided near where families with young children live and the number of other young children living nearby those providers potentially competing for the supply, the travel time required to reach that supply, and the cost and quality of the supply. We use Census data on the population of Minnesota families with young children combined with data on all the state's licensed center and family child care providers, public preschool, and Head Start providers. Our distance-based measures do not implicitly restrict families from crossing administrative boundaries in accessing nearby ECE services. Our quantity measure uses an enhanced two-stage floating catchment area design (Luo & Qi, 2009), which formalizes the idea that greater access for a family means having more supply closer by with fewer other children potentially competing for that supply. It captures variation in the nearby supply of ECE services from families' perspectives adjusting for the child population nearby each provider, where "nearby" is determined by drive time.

We extend the logic of this approach to propose new measures of families' cost of access to ECE services and the quality of ECE services accessible to families. The cost-based measures reflect both the monetary price of care and the cost of travel between the family's location and each nearby provider. The quality measure is basically a family-specific average of local provider quality. Each of these dimensions of access – quantity, cost, and quality– is different and important. Together, they give a holistic, textured view of ECE services from families' perspectives. While other factors influence families' selection of ECE providers, such as the hours of care (for example, whether evening or weekend hours are needed and offered), the cultural and language fit, and even whether the family has information about the provider, these are beyond the scope of this study (Carrillo, Harknett, Logan, Luhr, & Schneider, 2017; Davis & Connelly, 2005; Han, 2004; Kim & Fram, 2009; Liang, Fuller, & Singer, 2000; Peyton, Jacobs, O'Brien, & Roy, 2001; Radey & Brewster, 2007).

These new methods measure access to ECE services at a particular location, characterize it across subpopulations of families with young children, and enable examination of disparities in access for different groups of families defined by combinations of geography, racial and ethnic background, and income level. We demonstrate this approach using data from Minnesota in 2015 to estimate these measures among different communities in the state and make comparisons across different kinds of families.

Literature Review

A number of studies have shown how child care supply varies across communities in ways associated with community characteristics. Notably, child care availability is lower in rural areas and in lower-income communities compared to urban and higher-income areas (Cochi Ficano, 2006; Gordon & Chase-Lansdale, 2001; Hofferth & Wissoker, 1992). Other studies have found disparities across communities in the availability of preschool options (Bassok & Galdo, 2016), particularly high-quality settings (Bassok et al., 2011).

While there is widespread acknowledgement of the local nature of child care markets (Queralt & Witte, 1998), operationalizing what is meant by *local* has been a challenge. Chipty & Witte (1998), for example, use distance between child care centers (based on fivedigit ZIP code) to define child care markets. Based on a nationally-representative sample, the National Survey of Early Care and Education estimated that, on average, families used center-based arrangements within five miles of home for children under age 6 (National Survey of Early Care and Education Project Team, 2016). A number of recent studies have mapped information on the geographic locations of child care providers, often to provide information to parents about local care options (Alexander et al., 2016; Hardy et al., 2016). For example, a recent report provides a map of school-based and licensed center-based and family child care programs for two ZIP codes in Minneapolis (Overson & McConnell, 2015). A related study looks at inequality of access to child care using a "spatial mismatch" approach, analyzing the distribution of child care centers to that of families with young children by ZIP code, which fundamentally is an area-based measure (Covington, 2007).

A number of studies have focused on access to high-quality settings and the role of child care subsidies or public funding in facilitating access. Hatfield et al. (2015) examined differences in access to high-quality ECE across communities in North Carolina by estimating the relationship between the quality of ECE programs and community characteristics and funding sources. The study found that higher quality centers (those with higher scores in the quality rating system) were more likely to be located in more affluent communities and generally received more funding from Head Start and public preK funds. Johnson, Ryan, & Brooks-Gunn (2012) highlighted the importance of cost to families in determining access and the variation in quality across private and publically funded programs. They found that families receiving child care subsidies used higher-quality settings than similar families who did not use publically-funded ECE, yet the subsidized families also used lower-quality care compared to those in public programs such as Head Start. Marshall, Robeson, Tracy, Frye, & Roberts (2013) found that families in Massachusetts who received child care subsidies reported higher-quality care than similar families on the subsidy waiting list, and were more satisfied with care. While there is no single measure or definition of access in the literature, these studies highlight the importance of cost and quality to families as important aspects of measuring access.

Despite the popularity of area-based measures in the child care literature, the key limitation of these measures stems from the fact that the unit of analysis is based on administrative or political boundaries that are arbitrarily defined from the perspective of families deciding on child care for their children. McLafferty (2003) provides an analogous discussion of area- and distance-based measure of access in the health care literature. Area-based measures of access to ECE supply typically measure access by area using the area's ratio of the total number of slots divided by the total number of children or ratio of children to child care workers (Bassok et al., 2011; Fuller & Liang, 1996; Gordon & Chase-Lansdale, 2001; Neidell & Waldfogel, 2009). The potential for information loss and statistical bias when using area-based measures is known as a modifiable areal unit problem (MAUP) and has been a longstanding concern in geography (Gehlke & Biehl, 1934; Openshaw, 1984).

This Study

In contrast to much of the prior literature's reliance on area-based measures of access, this paper develops distance-based measures. However, distance-based measures presume knowledge of both ECE provider locations, which are commonly known, and family residential locations, which are generally geographically-bounded but not known exactly. To protect privacy, public data on families is available only by area, for example, counts by families by type within a Census block, block group, or tract. We approximate the distribution of family locations by combining that information with an assumption that families are uniformly distributed within a Census block (outside known, non-residential areas such as lakes, rivers and state parks). This approach harnesses all available data on

Census blocks' shapes and locations and the distribution of family types across Census spatial units, along with data on the road network and nonresidential areas.

We demonstrate that our distance-based measures of access provide a more accurate description of the set of provider choices near to the family, as some of the providers may be located near a family but across an administrative boundary. While we estimate that only 16% of households would have to cross a county line to get to the closest higher-rated provider in our data, 71% of households would cross census-tract boundaries and 87% would cross a census-block-group boundary line. Measures of access to child care based on administrative boundaries miss many options relevant to families. To illustrate this issue, our analysis will compare results obtained with the same data under distance-based and area-based measures. Appendix A.1 presents a simplified example comparing the two approaches.

Data, Measures and Methods

Data on Child Care Providers

Data on ECE providers in Minnesota in 2015 were obtained from the NACCRRAware data system managed by Child Care Aware of Minnesota (a child care resource and referral network). Information on each provider in the dataset includes total licensed capacity, enrollment by age group, prices by age group, and street address. The dataset identifies four types of providers: (i) child care centers (CCC), (ii) family child care (FCC), (iii) Head Start and Early Head Start programs, and (iv) School Readiness pre-kindergarten programs run by school districts. We group (iii) and (iv) into a public provider category. Public providers that operate more than one program at the same spatial location were counted as one provider. Private providers (CCC and FCC) are those not identified in the data as Head Start, Early Head Start or school-based programs.

In order to create access measures based on quantity and cost, we need information about each provider's capacity and prices in addition to its location. For private providers, the quantity measure for children age 0 to 4 is based on the provider's total licensed capacity minus current school-age enrollment. While providers may prefer to enroll fewer than their licensed maximum, this number represents the highest possible number of young children that can be served onsite at a time.[1] For public providers – both Head Start and school-based pre-kindergarten and preschool programs, information on location is provided but data on capacity are less available. One quarter of the Head Start programs are missing capacity information, so we use the median capacity in Head Start programs by region to impute capacity to these programs. For school-based programs, very few report capacity information. The few who do so report capacity of about 20 children per program. We use this number, approximating one classroom, to impute capacity for each school-based program. This data limitation warrants caution in interpreting the access measures for public ECE providers.

For the purposes of this study, provider quality is measured by ratings in Minnesota's Quality Rating and Improvement System (QRIS), called Parent Aware. The star level that a program receives is based on points earned in four domains: physical health and well-being; teaching and relationships; assessment of child progress; and teacher training and education (Cleveland, Li, Orfali, & Tout, 2016). Programs that choose to be fully rated receive financial and coaching supports. An initial evaluation of the Parent Aware system concluded that the star-rating system identified important differences in quality practices across programs (Tout et al., 2016). Whether these criteria are in accord with parents' perceptions of quality is an important issue but is beyond the scope of this study (Cryer, Tietze, & Wessels, 2002).[2] Information on Parent Aware ratings (one to four stars) for those providers who voluntarily

[1] Note: Most prior studies on access use total licensed capacity and do not state whether they adjust for school-age children, except to the extent that they do not include school-age only programs.
[2] There is an extensive literature that examines how to define, measure and improve child care quality and that investigates the linkages between quality and child outcomes (see, for example, Cassidy et al, (2005); Peisner-Feinberg et al, (2001))

participate is included in the dataset. Providers who did not participate in Parent Aware as of 2015 have no rating information. While we acknowledge that these providers may be of any quality level, we group them together into an “unrated” category.

To calculate a weekly access cost measure, we aim to measure the price for weekly, full-time care at each provider. Private (or market-based) providers report prices by age group: infant, toddler, preschool age and school age. To distill this information into a single price for each provider for the care of young children, we use weights based on the number of months a child age 0 to 4 would spend in each age group based on Minnesota regulations. For example, in a family child care setting, infants are children 12 months and younger, toddlers are aged 12 to 24 months, and preschool age is 24 to 60 months. Thus, we measure each family care provider’s weekly price as a weighted average of its infant, toddler, and preschool weekly prices with weights 12/60, 12/60, and 36/60, respectively. A similar process is used for child care centers with slightly different weights because the regulatory age-group definitions differ. Substantive results of the analysis are similar if we focus on one price, such as the price for preschool-age children, instead.

Forty percent of private providers do not report prices on a weekly basis, but instead report hourly or daily prices. These prices were converted to a weekly basis using the ratio between weekly and daily prices or between weekly and hourly prices in the market among providers that report prices in both time units. For private providers missing all price information (27.8%), prices were imputed by scoring their observed characteristics using a spatially-weighted regression of price controlling for type of care (center or family child care), location, Parent Aware quality rating (if rated), and provider’s years of experience estimated using the providers with both prices and characteristics observed. Additional details on conversion of prices to weekly rates and imputation of missing price information are in Appendix A.2. Price information was available for March, June and September 2015. We average over the three months for each provider to obtain a 2015 price.[3] The data do not contain price information for public providers. We assume they have a zero money price for parents. Any payments by parents for public programs are not observed but would be easy to integrate into the analysis if they were.

Characteristics of the ECE providers in Minnesota in 2015. There are about 12,000 ECE providers in the dataset, covering nearly all of the licensed providers in Minnesota in 2015, though new providers may be delayed in entering the dataset and systematic data are not available on friend, family and neighbor care. As shown in Table 1, only 10% of all licensed providers are private child care centers, with an average total licensed capacity of 66 slots. Nearly 6% of providers are Head Start and public pre-kindergarten programs, which we group together as "public" programs, with an average capacity of 28 slots. The majority of providers (84.2%) are family child care providers with an average capacity of 9.3 slots for children age 0 to 4. Among private providers, both centers and family based, weekly prices ranged from an average of $153 for infants to $136 on average for preschool age children. To examine regional differences, we compare the Minneapolis-St Paul metropolitan statistical area (MSA) and "Greater Minnesota," which includes more rural parts of the state as well as smaller metropolitan areas. Nearly half of the providers (47%) are located in the 11-county metropolitan area around the cities of Minneapolis and St. Paul.

We divide providers into three groups: 1) highly rated market providers, which includes providers who have a three- or four-star rating in Parent Aware and are not a public provider; 2) public programs, such as Head Start, Early Head Start, and School Readiness pre-kindergarten programs which are designated as highly rated (four stars) in the Parent

[3] For most providers, the prices are updated once per year in the database. Given the small differences in prices across the three quarters, it made little difference whether we averaged or used the most recent value.

Aware system and also do not report a price charged to parents; and 3) all other providers, which includes both unrated providers, i.e., those who do not have a rating in the voluntary Parent Aware QRIS and lower-rated programs that have a one- or two star rating in Parent Aware. This three-way classification allows us to focus on the two important dimensions: first whether the provider known to be highly rated, and second, whether they charge parents or are a public program. A large majority (83.4%) of providers were not rated in the Parent Aware QRIS in 2015 as the voluntary system has been rolling out over time (Cleveland et al., 2016). While unrated providers can be of any quality level, as the QRIS expands over time, future analysis will be able to examine quality differences more fully.

Data on Families and Family Locations

To construct distance-based measures of families' access to child care, the ideal dataset would have exact residential locations of all families with young children as well as information on their socio-economic characteristics. Exact locations, income and race of actual families with children under age 5 are not available due to privacy concerns. We approximate the spatial distribution of families' residential locations and their demographic characteristics by combining information from the Census American Community Survey (ACS) 2011-2015 five-year estimates (2015 ACS) and the 2010 decennial Census (Manson, Schroeder, Van Riper, & Ruggles, 2017).

In particular, we estimate the joint distribution of race, income, and number of children under 5 for families in each Census block combining data from the 2010 decennial Census and 2015 ACS using assumptions and methods detailed in a technical Appendix A.3 and described briefly here. From the 2015 ACS, we obtain recent estimates of the number of families with any child under age 5 by census block group. To get more exact geographic information about where families with young children live, we incorporate block-level data from the 2010 decennial census. Census blocks cover much smaller areas than Census block groups or tracts (see Table 2). The likelihood of a synthetic family location being in a particular Census block is proportional to the estimated likelihood that a real family with children under age 5 lives in that block. The exact location of any synthetic family within a block is random assuming a uniform distribution of families within the block boundaries.[4] We restrict the possible locations for synthetic families to exclude lakes, rivers and state parks.

To model the distribution of families within block groups accounting for racial clustering, we assume that, conditional on race, the distribution of families with young children across blocks within block groups is the same in 2015 as in 2010. In essence, we apply the race-income joint distribution among families with a young child at the lowest-available geographic level to any sub-units in order to estimate the joint distribution of race, income and location of the synthetic sample. We use 2015 ACS census tract-level estimates of the joint distribution of race and income among families with young children to approximate the race and income of families at the block level.

The ACS estimates that 259,503 families with children under age 5 lived in Minnesota in 2015. With about 12,000 ECE providers, the number of provider-family location pairs is extremely large, approximately 3 billion pairs. For computational ease, we draw a set of synthetic family locations numbering one quarter of the total number of Minnesota families (N=64,875 synthetic family locations), so each location represents four families. The 64,875 family locations are randomly drawn based on the estimated number of families with young children living in each Census block. For each family, we impute their number of children under 5 equal to their block group's average number of young children per family with any young children. At the end, each synthetic family location has an

[4] We use Geospatial Modelling Environment (GME) software for assigning family locations.

associated number of young children equal to four times the block-level average and a joint probability distribution over race and income level.

Travel time between each synthetic-family location and any ECE provider is estimated using **osrmtime**, a Stata command that calculates driving time between two geocoded points (Huber & Rust, 2016).[5] When computing travel time, the algorithm locates the nearest point on the road network and travel times are computed from that point. This functionally excludes locations off the road network and ensures the assignment of synthetic families to random habitable locations within a block. For each synthetic family location, the travel time to each provider within 20 minutes driving time is calculated. For 477 families of 64,875 total, there are no providers within 20 minutes driving time. For these families, we search farther, find the closest Minnesota provider of each of our three types, and include these.

Access Measures

Quantity measure: Slots adjusted for nearby population. We create a measure of nearby supply adjusting for the number of children nearby each provider using the enhanced two-stage floating catchment area (E2SFCA) method pioneered in geography (Luo & Qi, 2009). A commonly-used measure of the quantity of child care accessible to a family is the number of "slots per tot" – the total capacity of providers (slots) divided by the number of young children – in a particular area. Our measure differs in that it is family-centered and assumes families are interested in nearby providers whether or not they are located in the same area. The E2SFCA method measures the supply of slots within a family-specific

[5] Note: *osrmtime* takes advantage of two tools: 1. Open Source Routing Machine (OSRM) and 2. OpenStreetMaps. Both are provided by the open source community. Unlike Google Maps which considers real-time traffic obstacles in calculation of travel time, OSRM is a static routing machine and estimated travel time between point A and B can thus be replicated. We compared the travel time estimates of 2,000 random location pairs from *osrmtime* to the estimates from Google Maps and found the correlation of the estimates from the two sources was 0.97.

catchment area and adjusts each nearby provider's capacity based on the number of young children nearby that provider who might compete for the provider's slots. The two stages refer to the two catchment areas: first one for the provider and then another for the family (Luo & Wang, 2003a, 2003b). The measure for each family *i* is computed as follows:

Stage 1: Calculate the capacity-to-population ratio for each provider. For each provider j, find all families within the 20-minute drive-time catchment area around the provider's location. Denote these families as $\{i: t_{ij} \leq 20\}$ and the estimated number of young children in family *i* as P_i. Summing across families would give the number of young children nearby provider *j*, which proxies for the strength of potential demand for provider *j*'s slots. However, children closer to a provider are more relevant to provider demand, so we discount farther away children using the Gaussian distance decay function:

$$f(t;\beta) = e^{-\frac{t^{\beta}}{1000}}$$

β is a friction-of-distance parameter such that the relative weight on farther cases decreases with value of β.

We divide provider *j*'s number of slots (S_j) by the sum of (distance-) discounted child population to obtain a slots-to-(nearby young child) population ratio for provider *j*:

$$SPR_j = \frac{S_j}{\sum_{\{i:t_{ij} \leq 20\}} P_i \times f(t_{ij};\beta)}$$

Two providers with the same capacity will have different SPRs if one has more young children nearer by. This measure captures the notion that a provider's slots will be less accessible to any nearby family if more children are closer to the provider competing for the slots.

Stage 2: For any family *i*, measure the quantity of its local supply based on the total capacity of nearby providers adjusting for their nearby young-child population. Identify all ECE providers within the 20-minute catchment area (or the nearest providers outside that travel time if none are within it): $\{j: t_{ij} \leq 20\}$. Compute each one's slots-to-population ratio discounting for travel time using the same distance-decay function: $S_{ij} \equiv SPR_j \times f(t_{ij}; \beta)$. Summing these across the providers nearby to family *i* yields the family's measure of access to ECE supply, $S_i \equiv \sum_{\{j: t_{ij} \leq 20)} S_{ij}$. We will refer to S_i as the family's measure of *nearby supply adjusted for nearby population* or simply *adjusted supply*. It increases if the family has more slots nearer by and decreases if more young children are nearer by those slots. It is very similar in spirit to the area-based slots-per-tot measure, however, it is family-centered and distance-based. A measure of family's access to adjusted supply from each type of provider can be obtained simply by summing only across providers of that type.

For the Gaussian decay function, we use a distance-weighting factor of four (*β*=4). A recent, nationally-representative survey on child care found that most children (60%) have nonparental care within three miles of their home. In addition, families using child care centers report that the average travel distance from their home to their child care center was about four miles (National Survey of Early Care and Education Project Team, 2016). Our measures are based on travel times rather than straight-line distances, nonetheless, the evidence suggests that most families do not travel far from home for child care. Using *β*=4 puts the majority of weight on providers within 10 minutes of the home location, and relatively less weight on those between 10 and 20 minutes away. In contrast, a factor of two, for example, would put more relatively weight on providers between 10 and 20 minutes from the family than with a weight factor of four, although it would still weight providers within 10 minutes more heavily than those farther away. Our basic results are not sensitive to the distance weight chosen.

Cost measure: Total cost of access. Though quantity-based measures provide important information about access to ECE services, families' access also depends on the cost of ECE services. A family's costs to use a particular provider include both the value of time necessary to travel to the provider and the money price charged. We define the weekly total cost of access at a specific provider for a specific family to be the sum of the weekly travel costs plus the price of weekly full-time care reported by the provider. Weekly travel time is estimated by multiplying the one-way travel time in minutes (t_{ij}) by 10, to capture five round trips per week. Divide travel time in minutes by 60 to express in hours rather than minutes. We use $10 per hour to capture the opportunity cost of time. Thus, weekly travel cost is 10 dollars per hour times $t_{ij}/60$ hours per trip times 10 trips per week. The weekly money price of full time care is provider-specific and measured as described previously in the section on providers. The total cost of access for family *i* at provider *j* (C_{ij}) is the sum of the travel cost and money price. Combining travel cost and money price into a total cost measure is a transparent way to account for the fact that prices may be higher in urban areas but travel times longer in rural areas. In contrast, conventional area-based measures of cost, such as average price in area, ignore travel costs, assume all in-area providers are equally relevant to each family, and assume all out-of-area providers are irrelevant.

We summarize the total cost of access in the local market for each family in two ways: first by looking only at the nearest provider, and second, by looking at an adjusted-supply-weighted average of nearby providers. First, one straightforward measure for each family is the cost to access the single provider closest to the family, that is, the provider with the shortest drive time to the family location. Using this measure, the family's access cost will decrease if a new provider opens closer to the family at the same price or if the closest provider's price decreases. The closest-provider cost measure provides a simple summary of cost in the ECE market near the family, but does not account for differences in capacity or child population nearby.

Therefore, we also measure the total access cost (and its components) using a family-specific weighted average across nearby providers. From the perspective of any family *i*, each provider *j*'s adjusted supply, i.e. their discounted slots-to-population ratio (S_{ij}), expresses the importance of provider *j*'s capacity in absolute terms. Difference between two providers' S_{ij} expresses difference in the relative importance of their capacity to family *i*. Let J_i denote the number of nearby providers, those in $\{j: t_{ij} \leq 20\}$. For each family, we compute an average cost of accessing nearby providers weighting by adjusted supply (S_{ij}):

$$C_i = J_i^{-1} \sum_{\{j:t_{ij} \leq 20\}} \frac{C_{ij} * S_{ij}}{\sum_{\{j:t_{ij} \leq 20\}} S_{ij}}.$$

Both the closest-provider and the adjusted-supply-weighted average approaches summarize the costs of access in the local market for a family at a particular location. Cost based on closest provider is easy to understand but less comprehensive and robust than the weighted average.

Quality measure: Highly-rated share of local (adjusted) supply: Given provider-specific measures of quality, the quality of the ECE market around a particular family location can be computed using either of the same two weighting schemes described above for total cost: give all weight to the single closest provider or use adjusted supply as a provider weight to calculate the average quality of nearby providers. We start with a provider-specific indicator of being highly rated in Parent Aware. For each family, we then measure if the closest provider is highly-rated and measure the adjusted-supply-weighted average of the indicator, yielding a measure of the share of nearby slots that are highly-rated. Minnesota's Parent Aware QRIS was rolled out over time, reaching all counties only in 2015. As a result, the participation rate of providers was relatively low in 2015. Our results demonstrate the concept of building family-specific quality measures but caution is warranted in drawing substantive conclusions from the specific results. The method can apply to any available quality measure, such as a QRIS rating, an indicator of accreditation, an observational rating, a set of indicators of compliance violations, child:adult ratio, or educational credentials of the teachers.

Analysis Methods

The main analytic approach uses a cross-sectional design and descriptive statistical analysis methods to compare the measures by location and demographic subgroup. We calculated means and distributions for each of the measures (adjusted supply, total cost, weekly price, travel time, and highly-rated share). These measures were analyzed overall and for different provider types (child care center, family child care, and public provider or highly-rated private, public, and other providers) and for different locations and race, ethnicity, and income subgroups. We conduct standard difference-in-means statistical tests for differences across subgroups using bootstrapped standard errors.

Results

Quantity: Adjusted supply

Table 3 shows the results for adjusted supply. The average family with a young child in Minnesota lives in a location with slightly more than half a slot nearby (0.56) adjusting for the number of other young children nearby each slot. More simply, the average family has access to about half a slot per child. Turning this around, there are nearly two nearby children for every slot of capacity. Although this phrasing sounds similar to that referring to a area-based, slots-per-tot measure, the measure is operationalized very differently.

Overall, there are fewer ECE providers in Greater Minnesota, however there are also fewer children competing for the slots of those providers. As a result, the adjusted supply measure is significantly higher for families in Greater Minnesota (0.64) than for those in the

Minneapolis-St. Paul metro area (0.51). Families in Greater Minnesota have less access to supply in private child care centers, 0.14 slots per nearby child for families in Greater Minnesota compared to 0.28 for families in the Minneapolis-St. Paul metropolitan area. Thus, the distribution of families' access to adjusted supply across the three categories of ECE providers (centers, family child care and public providers) varies across the state's two regions. A larger share (56%) of adjusted supply is in private child care centers for families in the Minneapolis-St. Paul metro area compared to families in Greater Minnesota (21%). However, families in Greater Minnesota have a higher level of access to adjusted supply from public slots than do families in the Minneapolis-St. Paul (0.10 slots per nearby child compared to 0.03 slots per nearby child) and a higher share of their supply from public slots (16% compared to 6%).

Small different levels of adjusted supply are observed across families in different income groups. Compared to families with income less than the federal poverty line (FPL), both middle income (defined as families with income above FPL and less than 185% of FPL) and higher income (defined as families with income above 185% of FPL) have lower overall access. These differences are statistically significant but not large in magnitude (0.59 vs. 0.56 vs. 0.55 adjusted slots per nearby young child). Low-income families have more access to public capacity relative to middle and higher income families (0.081 vs. 0.066 vs. 0.051 adjusted slots). The higher adjusted supply of public capacity near low-income families may reflect intentionally higher public investment in ECE capacity in low-income communities (Fuller & Liang, 1996). Private supply in child care centers and family child care homes is similar across the income categories.

Average adjusted supply is similar across the six racial and ethnicity categories defined in the American Community Survey, and is highest for American Indian families, due to more adjusted supply from public providers (Table 4). Access to private child care center slots is lower for white families and American Indian families compared to those of other groups, in part because these families are disproportionately located in rural parts of the state with fewer centers. Public slots make up about 9-10% of adjusted supply for white (non-Hispanic), African-American and Hispanic families compared to 35% for American Indian families in Minnesota.

This new adjusted measure of supply can be used to analyze variation in smaller geographic areas as well as for different subgroups of the population. The adjusted supply measure is calculated for each synthetic family location and can be plotted on a map to illustrate spatial patterns of supply access. Families living in locations with higher values of adjusted supply have higher ECE access in the sense of geographical proximity to greater supply due to a combination of more slots at nearby providers, providers closer by, and fewer other children closer to those providers. Synthetic family locations and families' adjusted supply values can be plotted on a map to illuminate spatial patterns of access to adjusted supply.

Adjusted supply varies considerably around the state, but images of the statewide map are difficult to see in print. Instead, we illustrate the spatial pattern in two counties, Hennepin and Ramsey, which contain the cities of Minneapolis and St. Paul, respectively, along with some nearby suburbs. In Figure 1, each dot on the map represents the location of a synthetic family. Green dots indicate family locations with higher access to adjusted slots and red dots indicate lower access. Each color on the map contains an equal number of synthetic families grouped into five quintiles of the adjusted supply measure. Recall that adjusted supply is based on the driving time area around the family's location and is not restricted by census-tract boundaries, although these boundaries are shown on the map for reference. The density of the dot clusters represent the residential density of families with young children. Dense clusters of red indicate areas where both (1) many young children live and (2) the families have relatively little adjusted supply nearby. Seeing the spatial pattern of families' locations with their adjusted supply allows planners, policymakers, and entrepreneurs to identify areas where investments in additional capacity may be desirable.

Total Access Cost

Though measures of supply provide important information about access to ECE services, access also depends on cost to the family. We first summarize the cost of access in the local market for each family by calculating the cost to access the provider closest to the family's location based on driving time. Using this approach, we find that on average in Minnesota there is a provider within two minutes driving time of families with young children, usually a family child care provider (Table 5). Travel time to the closest child care center is higher than for the other types of providers, averaging over seven minutes statewide. Not surprisingly, families in Greater Minnesota, which is more rural, face longer average driving times to their closest provider than do families in the Minneapolis-St. Paul metro area. Driving time to the closest ECE provider for metro families averages just over one minute compared to over three minutes in Greater Minnesota.

At the closest provider to the family, the average weekly price follows expected patterns. The average price is higher for families' closest child care center than for their closest family child care provider, and average prices are much higher for families in the Minneapolis-St. Paul metro area than for Greater Minnesota families. Combining the travel costs based on driving time and weekly price, the total cost to access each family's single closest provider averages $151 statewide. Not surprisingly, the total costs varies considerably across the provider types. To access the closest child care center, families statewide would incur an average cost of nearly $222 compared to the average cost of $148 at families' closest family child care provider. Public providers are assumed to have zero money prices for families and, therefore, access costs are based only on travel time.

The measures based on the closest provider to the family location provide useful summary information about the ECE market near the family, but do not account for differences in capacity or child population nearby nor do they represent families' view of the larger ECE market beyond their single closest provider. Using the adjusted supply measure described in the previous section as a provider weight, we re-examine the total cost (and its components) using an average across providers nearby each family's location. Closer providers, those with more capacity, and those with fewer children nearer by them are weighted more heavily than others. Results are summarized by region and by income in Table 6.

Including additional providers mechanically raises the average driving time compared to the closest-provider measure but the spatial patterns are similar across the two methods. Families are farther from child care centers, especially in Greater Minnesota, with average weighted driving times nearly four minutes longer than to family child care providers. Weekly prices are slightly higher when weighted by adjusted supply compared to the average price of the closest provider, but the patterns across types of care and regions are the same. The total cost to Minnesota families averaged $172 per week statewide for all types of care, with higher costs for accessing centers than family child care (or public providers). For families in the Minneapolis-St Paul metro area, the average total cost is $261 for center-based care compared to $170 for family child care.

Families with low incomes tend to have slightly shorter average driving time compared to middle and higher income families, and slightly but significantly lower total cost regardless of provider type (table 6). The total (weighted) cost to access a child care center is $220 on average for a low-income family compared to $232 for families with incomes above 185%FPL. Note that in general, the differences in the measures by income group are smaller than the differences by region.

Comparing the total costs of access across race and ethnicity subgroups, we see similar patterns across the types of providers, with access costs highest for child care centers and lowest for public providers (Table 7). Similar cost patterns are seen for the race and ethnicity categories whether using only the closest provider or the adjusted-supply provider weights. The total costs to access center or family child care are lower for American Indian families than other groups because of lower prices nearby. In contrast, longer drive times result in higher travel costs to public providers for American Indian families. To access nearby child care centers, white, non-Hispanic families would need an average of $224 per week compared to $258 for African-American families and $265 for Asian families. Average costs to access centers are similar for Asian families ($227) to white non-Hispanic families ($224), and lower for American Indian families ($204). Because ECE prices are higher in the Minneapolis-St. Paul metro area, groups whose population is more heavily concentrated in the metro area face higher prices and higher total access costs.

Access to Quality

We next use these measures to evaluate access to highly rated providers across regions and socio-demographic groups. Providers are categorized in three groups: highly-rated private providers (those with a three- or four-star rating in Parent Aware who report prices), public providers (which are Head Start, Early Head Start or school-based prekindergarten programs), and all other providers (including child care centers and licensed family providers who have no rating or a one- or two-star rating).[6] Results for the quantity and cost measures for these three groups are shown in Table 8. Families in the Minneapolis-

[6] ECE providers who are not rated in the Parent Aware QRIS may be high quality but have not volunteered to participate in the rating system. Note, however, that the unrated providers and lower-rated providers have similar prices on average. We combine the unrated and lower-rated providers in order to distinguish them from the providers who are highly rated in the QRIS. We keep public providers separate from other highly-rated providers because of the poor quality of data we have on capacity, enrollment, and price for the public providers, resulting in less confidence in the results for public providers.

St. Paul metro area have access to an average of 0.13 adjusted slots at highly-rated private providers. In other words, there are about seven nearby young children for every highly-rated, private slot. Families in Greater Minnesota have access to far less highly-rated market supply, with an average of only 0.05 highly rated private adjusted slots nearby. The opposite geographic pattern is seen for public providers, who are also highly rated in the Parent Aware QRIS. Families in Greater Minnesota average 0.10 adjusted slots of public supply while families in the Minneapolis-St Paul metro area average only 0.03. Combining both market and public sources of highly-rated supply, the share of adjusted slots that are highly rated is slightly higher for families in the Greater Minnesota (31% versus 28%) and a larger proportion of those are public providers.

Travel times to highly-rated private providers are much longer, on average, for greater Minnesota families than metro families (18 versus 6 minutes), but prices are considerably lower. Therefore, total access costs for highly rated private providers are considerably higher in the Minneapolis-St. Paul metro area relative to Greater Minnesota. The weighted average cost to access a highly rated private provider in the metro area is $274 per week compared to $171 in Greater Minnesota. Note that we can use the total access cost measure to calculate the "quality premium," that is, the cost to access a highly rated private provider (including both travel costs and weekly price) compared to other private providers. On average across the state the quality premium was about 1.36, or 36%, and was slightly higher in the Minneapolis-St Paul region (37%) compared to the rest of Minnesota (34%). Families would pay, on average, 36% more to access a highly rated private provider compared to a lower rated or unrated private provider.

Access to highly rated providers varies across income groups, although the differences are smaller than across regions. Families with incomes below the poverty line tend to have higher access to both highly-rated market providers and public providers. The quality premium is smaller for low-income families as well, 34% compared to 36% for middle and higher-income families.

Comparison of Area-based and Distance-based Measures

The new, distance-based measures account for the fact that families can cross arbitrary administrative boundaries, relaxing area-based measures' implicit assumption of impenetrable boundaries and better reflecting the real experiences of families and providers. Although area-based and distance-based measures could theoretically produce similar findings with regard to the spatial distribution of access, this is not the case in Minnesota. To demonstrate the difference, we compute both a standard area-based measure and our distance-based supply measure using the same data in the same geographic area (Hennepin and Ramsey Counties) and display the two results in Figures 2 and 3, respectively. In Figure 2, the number of slots per young child is calculated for each census tract, a standard area-based measure. In Figure 3, adjusted supply is calculated for each synthetic family in the census tract, accounting for providers within each family's drive-time proximity and the number of other children near that supply, whether or not the reference family, the providers, or the other families share a census tract. This adjusted supply measure is then averaged across families within each census tract to get a tract-level measure comparable to Figure 2's area-based measure. The colors in each figure represent quintiles of the distribution of the relevant measure.

By ignoring arbitrary administrative boundaries, the distance-based measure includes less noise than the area-based measure. Comparing the two maps in Figures 2 and 3, there are two important features demonstrating this difference. First, the distanced-based method generates smoother multi-tract areas of high or low supply because families are allowed to cross boundaries to get to nearby providers. The presence of a large provider in one tract is recognized as adding supply for nearby families in neighboring tracts. In contrast, with the area-based measure, the map shows starkly different values across neighboring areas as it spikes the numerator in one area but contributes nothing to access of families' in neighboring areas.[7] Second, the scales are different on the two maps, with the area-based measure having more extreme values. There is at least one census tract with no child care providers and, therefore, no slots within its boundaries (slots per child = 0) but in the distance-based approach, the minimum value is 0.14 adjusted slots per child. Similarly, at the high end of the range, one census tract has more than 18 slots per child, driven by a center located in a tract without many children. Yet families will come from nearby census tracts to that center. The distance-based measure of slots adjusted for nearby child population results in a different, more accurate map of areas with low and high relative supply. Whether area-based and distance-based measures will always show different results depends on the size of the geographic units used as the basis of the area-based measure and how close families and providers are located to the boundaries.

How do the three primary dimensions of families' access to ECE services – quantity, cost, and quality – relate to one another and how do these relationships differ when using distance-based measures versus area-based measures? Many underlying economic, demographic, or policy forces could induce correlation between the dimensions. For instance, areas with a greater quantity of care accessible might tend to have lower costs because of greater competition or higher costs because greater underlying effective demand in that community drew in extra capacity and raised prices. On the other hand, if no correlations are observed this could be either because the dimensions truly are uncorrelated or because noisy measurement attenuates the correlation.

[7] This is also illustrated in our example in Appendix A.1.

We examine the correlations for both distance- and area-based measures in Table 9. The analysis is done on variables averaged up to the Census tract level to ensure comparability between measure types. Overall the correlations are small, indicating that the cost and quantity measures are not closely related. Cost has a -0.11 correlation with quantity using distance-based measures (adjusted supply with total cost) and a -0.06 correlation with area-based measures (slots-per-tot with weekly price). The correlation based on weekly price is similar between the two measures (-0.08 versus -0.06) but the distance-based measure also incorporates the fact that less supply nearer by tends to raise travel costs (correlation between adjusted supply and travel cost is -0.35), and so raise the total cost of access. Highly-rated share has a 0.08 correlation with quantity under distance-based measures and a -0.02 correlation under area-based measures. While these correlations are small, the correlations among the distance-based measures are generally significantly larger (in absolute value) than those of the area-based measures. Very small correlations for the zone-based measures suggests they are noisy measures and not closely related to each other.

Discussion and Conclusion

This study, using GIS-based simulation methods, introduces new measures of access that are family-centered and reflect the quantity, cost and quality dimensions of access to early care and education services. The literature has acknowledged that the lack of data sources is the biggest impediment to the study of community-level child care accessibility (Gordon & Chase-Lansdale, 2001). Measures such as number of slots per child per county or number of child care workers per child within a 20-30 mile radius of the child's ZIP code of residence have been suggested as measures of child care availability across different communities in U.S. (Coley, Votruba-Drzal, Collins, & Miller, 2014; Gordon & Chase-Lansdale, 2001). Our study builds upon the previous literature on child care access measures by developing a GIS-based access measure that utilizes a distance-based approach. Using licensed child care provider data with detailed provider characteristics and simulated family locations (based on population and race data from the Census), we calculate travel time between families and neighboring providers to examine access disparities across locations and demographic groups in Minnesota.

Conceptually, the distance-based approach is intended to represent the family's view of the ECE market rather than the family's ability to access a particular slot. By using a family-centered approach, the measures improve upon existing area-based methods of measuring supply. Measures based on the number or capacity of providers within an area such as a census tract or ZIP code area provide insufficient information about the availability of providers close to families who live nearby but on the other side of the administrative boundaries. In some studies, area-based measures are dichotomized to identify areas with low supply or shortages (e.g., "child care deserts) versus those with adequate supply (Dobbins, Tercha, McCready, & Liu, 2016; Malik, Hamm, Adamu, & Morrissey, 2016). These approaches have the advantage of being relatively straightforward, transparent and emotionally impactful. No one wants children to be stuck in a desert. These designations may be misleading, however, because of the restriction of the area boundaries and the loss of information in converting from a continuous slots-per-child measure to a dichotomous desert-or-not measure. Another attraction, though not virtue, of the dichotomous measure is that it masks the underlying area-based measure's noisiness. In contrast, our new measures allow for crossing these boundaries and provide a smooth, continuous measure of supply adjusted for nearby population. Thus, while our adjusted supply measure is conceptually similar to a area-based measure of the number of slots per child in a given area, the view of variation in access may be more accurate as well as more nuanced using the new measure. While the new measures could be used to define a threshold for a child care desert, the continuous measure may provide more useful information for policymakers and planners.

These measures of supply provide important information about the availability of ECE providers nearby to families but a family's ability to access a particular provider also depends upon the cost to the family. Our total cost of access measure captures both the price the provider charges and the proximity to the family in dollar terms in a single measure. We demonstrate that total access costs to the family can be represented either by the cost to access the closest provider, or by using a weighted average of providers within a driving time catchment area around the family's location. The results show similar patterns using either approach. In the extant literature, a common area-based measure of cost is the average price of providers in an area, which ignores the spatial distribution of families and therefore gives a limited picture of the prices of providers nearby the family. Average price alone also ignores travel time costs.

Given a measure of quality of ECE services, similar quantity and cost measures can be estimated for providers of differing quality levels. While Minnesota's QRIS is relatively new and has limited coverage, in 2015 the differences in the adjusted quantity and cost of accessing highly rated providers in different regions of the state were large. The quality premium, as measured by the ratio of total access costs at a highly rated market provider relative to an unrated or lower-rated provider, provides a summary measure of the tradeoff a family faces in terms of cost and quality. This measure incorporates both travel costs and provider prices, and so measures how much more it would cost a family to access highly rated market-based care. Statewide, the quality premium is estimated to be 36%, indicating that families would incur costs 36% higher to access a highly-rated market provider compared to an unrated or lower-rated provider. The average premium estimated in this study is quite similar to the cost difference Mocan (1997) calculates (38%) for providing “good” quality child care services compared to “mediocre” quality (his cost difference was $243 to

$324 in 1993 dollars). The quality premium varies considerably across families, depending on how close they live to a highly rated provider, and the price charged.

The findings of this study suggests that conclusions one can draw about child care accessibility in different communities can sharply differ depending on how access measures are calculated. By using readily available ACS data and GIS tools to estimate household-to-provider distance-based measures, this study avoids the strict assumptions of area-based measures. The improved measures of accessibility yield better understanding of unmet childcare needs of different communities across the state.

Study Limitations

While this study provides new distance-based measures of access to high quality ECE, there are a number of limitations and directions for future research. An important limitation is that we do not have data on precise residential locations of families who are seeking or using child care; therefore, there is the measurement error in the locations and travel times. In addition, we are assuming travel from home to child care by car and are not able to incorporate travel between work location and child care or by other modes of transportation in the analysis. We do not have direct observational measures of quality, rather we rely on the state's quality rating system as an indicator of quality. Further, the low level of participation in Parent Aware among providers means that the "unrated" category includes providers of varying quality levels. As the Parent Aware QRIS system matures and more providers join, measured access to highly rated ECE will change. In addition, because of data limitations, the current study does not account for how public, voucher-based subsidies affect the cost of child care for some families. As better data become available on the capacity and site locations for public providers, we plan to expand the analysis of how public investments support access to high quality ECE.

The access measures derived in this paper are measures of the supply of child care and early learning opportunities. While these distance-based measures are a substantial improvement over current measures, they do not account for the availability of openings at the nearest provider, nor account for family preferences with regards to care provided by relatives, or specific language or cultural preferences. Despite these limitations, the access measures provide new insights into the access and affordability of early care and learning opportunities for families of different income levels and sociodemographic groups.

Conclusion

The concept of access is complex, and there is no commonly accepted definition or measure of access in the literature on early care and education. This paper expands our understanding of access by combining information on the locations of families and providers with data on prices to account for both costs and availability of supply. By developing new access measures that are centered on the family's location rather than a area-based aggregate measure, the results provide more accurate information on the communities in which families have better or worse access to early care and education. The new measures incorporate both cost and proximity to examine the options available to families. As the Parent Aware quality rating system expands in Minnesota, changes in access to high quality early care and education can be tracked. The spatial distributions of highly rated providers and families interact result in differential levels of access to quality ECE across geographic space. Families may live close to high quality providers, yet be unable to afford them. Information from these access measures can help give a rich multi-dimensional picture of the local market and be used by policymakers to determine where to support expansions of supply and other mechanisms such as subsidies and scholarships to improve access to high quality early care and education for all children.

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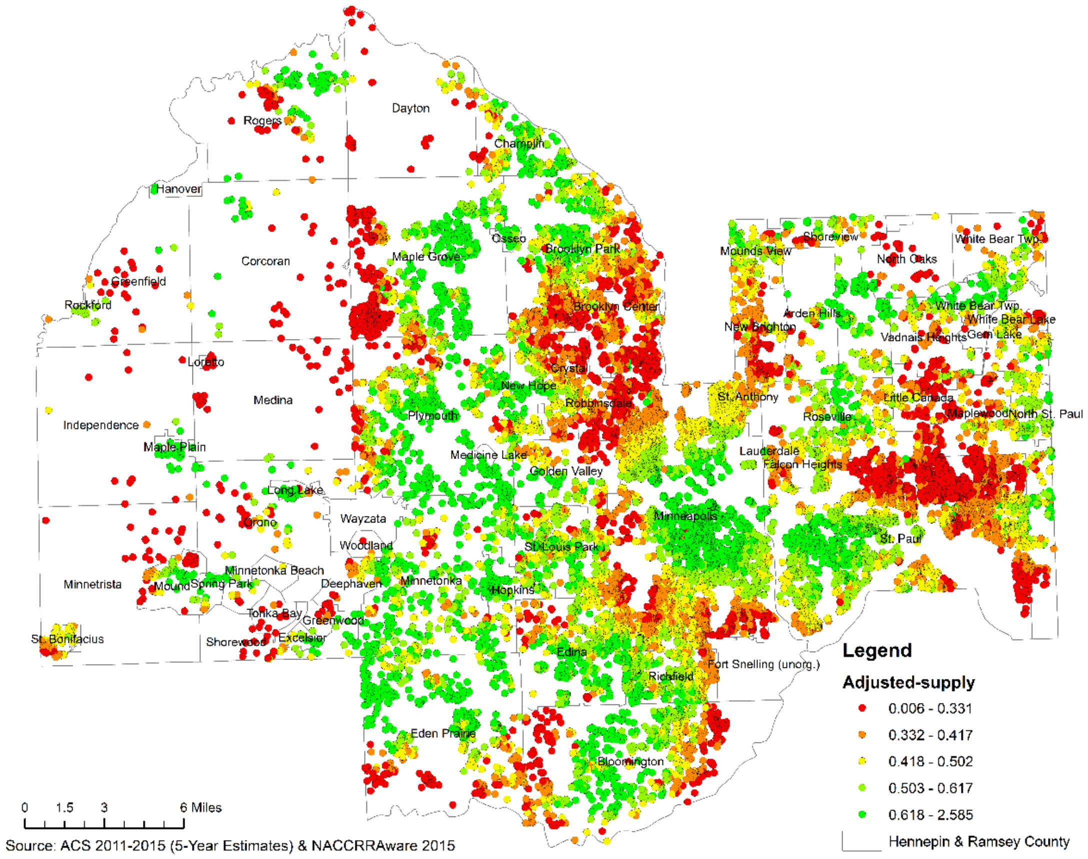
Figure 1. Spatial distribution of families' access to supply adjusted for local child population in Hennepin and Ramsey Counties, 2015



Note: The adjusted supply measure is calculated using the E2SFCA method with Gaussian weight beta=4 assuming a 20-minute driving time catchment area around each family location and each ECE provider.

Figure 2. Slots per child by census tract (area-based measure) in Hennepin and Ramsey Counties, 2015

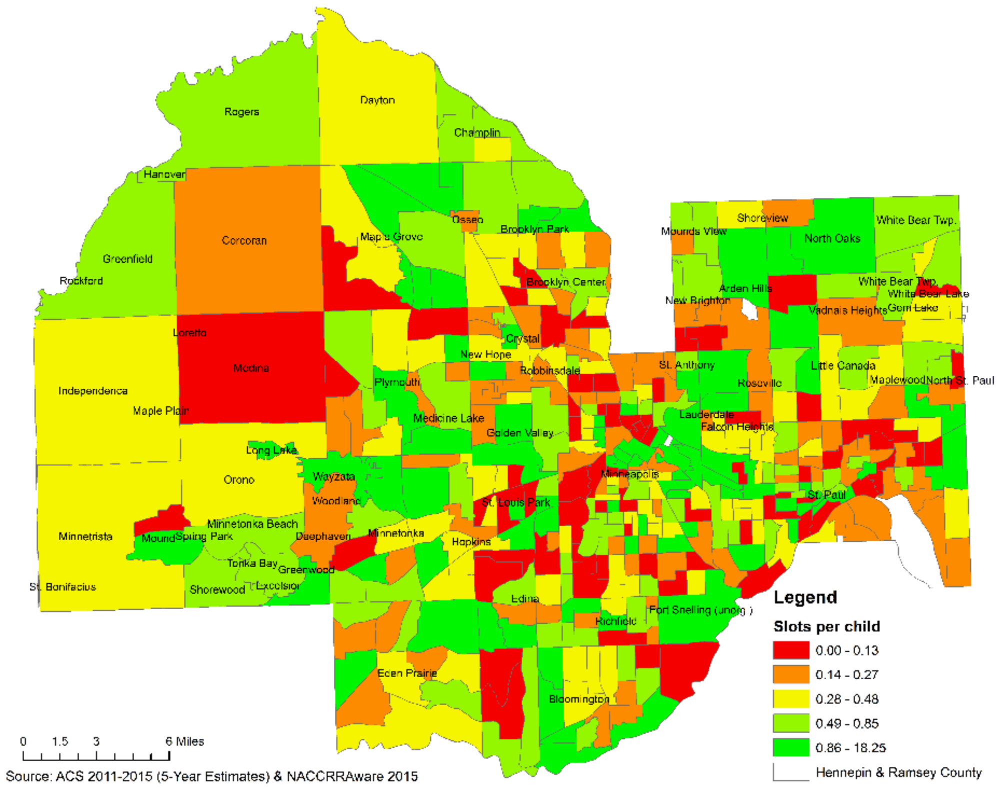


Figure 3. E2SFCA adjusted supply measure (distance-based measure) averaged by census tract, in Hennepin and Ramsey Counties, 2015

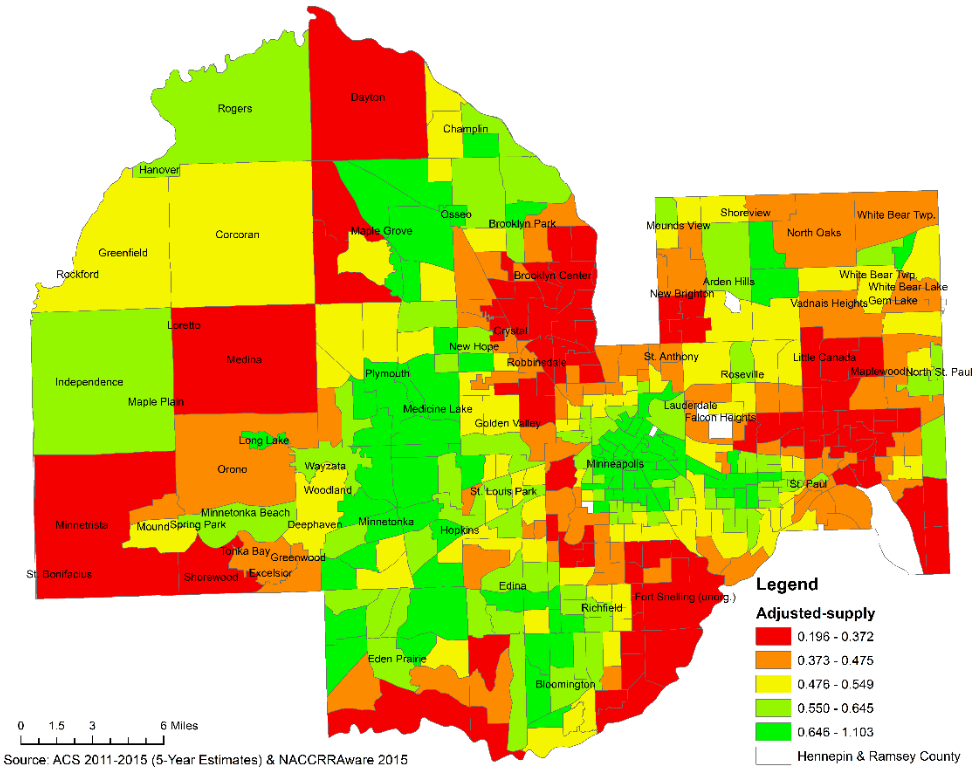


Table 1: Characteristics of ECE providers in Minnesota, 2015

	Mean	Std.Dev.
Family child care (share)	0.842	0.364
Child care centers (private) (share)	0.099	0.299
Public (Head Start or public preK) (share)	0.058	0.234
Weekly price - Infant	152.9	53.76
Weekly price - Toddler	143.9	45.6
Weekly price - Preschool age	135.8	41.9
Weekly price – Weighted age groups	143.1	45.04
Capacity - Family child care	9.33	1.65
Capacity - Child care centers (private)	66.47	39.43
Capacity - Public (Head Start or public preK)	28.25	41.58
Unrated and lower rated providers (share)	0.887	0.317
Highly rated providers (private) (share)	0.058	0.233
Minneapolis-St Paul MSA (share)	0.468	0.499
Number of observations (N)	11,989	

Notes: Provider rating is the provider's current star level in Parent Aware, if they are rated. Public providers are assumed to have a price of zero for parents (which are treated as missing in calculating the mean price in this table). The Minneapolis-St Paul metropolitan statistical area (MSA) is the largest in Minnesota and consists of 11 contiguous counties. The remaining counties in Minnesota are collectively referred to as "Greater Minnesota" and include more rural parts of the state as well as smaller metropolitan areas.

Table 2. Comparison of geographic levels and variables in Census data sources

	Geographic unit		
	Census block	Census block group	Census tract
Data source	2010 Census	2011-2015 American Community Survey 5-year estimates (2015 ACS)	2011-2015 American Community Survey 5-year estimates (2015 ACS)
Number of units in Minnesota	259,777 blocks	4,111 block groups	1,335 census tracts
(Mean) Size of geographic unit area, Minneapolis-St Paul MSA	0.05 sq. miles	2.1 sq. miles	6.7 sq. miles
(Mean) Size of geographic unit area, Greater Minnesota	0.4 sq. miles	39.9 sq. miles	135.6 sq. miles
Variables used	Number of families with children under 6, by race/ethnicity groups	Number of families with children under 5, by poverty status	•Number of families with children under 5, by poverty status within race and ethnicity groups •Number of families by 12 income categories

Table 3: Supply Adjusted for Nearby Children (Enhanced Two-Stage Floating Catchment Area Method) in Minnesota, 2015, by Region, by Income

	By Region			By Income		
	Statewide	Minneapolis – St Paul metro area	Greater Minnesota	Below FPL	Above FPL & Less than 185%FPL	Above 185% FPL
Slots adjusted for nearby children						
Any provider	0.558	0.509	0.636***	0.590	0.561***	0.551***
Child care centers (CCC)	0.227	0.284	0.135***	0.234	0.220***	0.226***
Family child care (FCC)	0.274	0.194	0.401***	0.275	0.275	0.273
Public providers	0.058	0.031	0.100***	0.0813	0.066***	0.051***
Share of (adjusted) slots						
Child care centers (CCC)	0.407	0.558	0.212***	0.397	0.392***	0.410***
Family child care (FCC)	0.491	0.381	0.631***	0.466	0.490	0.495
Public providers	0.104	0.061	0.157***	0.138	0.118***	0.093***

Note: The confidence intervals are computed using bootstrapping - based on 1000 repetitions (reference: MSA, Below Federal Poverty Line (FPL)): * p<0.1, ** p<0.05, *** p<0.01

Table 4. Supply Adjusted for Nearby Children (Two-Stage Floating Catchment Area Method) in Minnesota, 2015, by Race and Ethnicity Category

	White	African-American	Hispanic	American Indian	Asian	Other
Slots adjusted for nearby children						
Any provider	0.564	0.541***	0.562	0.636*	0.496***	0.534***
Child care centers (CCC)	0.21	0.323***	0.256***	0.155***	0.283***	0.26***
Family child care (FCC)	0.296	0.171***	0.247***	0.256*	0.172***	0.218***
Public providers	0.058	0.047***	0.058	0.224***	0.041***	0.056
Share of (adjusted) slots						
Child care centers (CCC)	0.372	0.597***	0.456***	0.244***	0.571***	0.487***
Family child care (FCC)	0.525	0.316***	0.440***	0.403*	0.347***	0.408***
Public providers	0.103	0.087***	0.103	0.352***	0.083***	0.105

Note: The confidence intervals are computed using bootstrapping - based on 1000 repetitions (reference White): * p<0.1, ** p<0.05, *** p<0.01

Table 5. Total Access Costs and Its Components Based on the Closest ECE Provider, Minnesota, 2015, by region

Mean	Statewide	Minneapolis-St. Paul metro area	Greater Minnesota
Driving time (minutes)			
Any providers	2.05	1.28	3.28***
Child care centers (CCC)	7.09	2.97	13.66***
Family child care (FCC)	2.27	1.47	3.54***
Public providers	5.58	4.51	7.30***
Weekly price (dollars per week) at closest provider			
Any providers	147.5	172.5	107.7***
Child care centers (CCC)	210.3	246.2	153.0***
Family child care (FCC)	144.2	162.9	114.3***
Public providers	0	0	0
Total access costs (dollars per week) at closest provider			
Any providers	151.0	174.6	113.2***
Child care centers (CCC)	222.1	251.1	175.8***
Family child care (FCC)	147.9	165.3	120.2***
Public providers	9.3	7.5	12.2***

Note: The confidence intervals are computed using bootstrapping - based on 1000 repetitions (reference: MSA, reference: * p<0.1, ** p<0.05, *** p<0.01; Weekly price is based on a weighted average of prices for each age group.

Table 6. Total Access Costs and its Components Based on the E2SFCA-Weighted Providers within 20-minutes Driving Time, Minnesota, 2015, by Region, by Income

	By Region			By Income		
	Statewide	Minneapolis – St Paul metro area	Greater Minnesota	Below FPL	Above FPL & Less than 185%FPL	Above 185% FPL
Driving time (minutes)						
Any provider	4.58	4.23	5.13***	4.3	4.6***	4.6***
Child care centers (CCC)	8.53	4.87	14.37***	9.1	9.1	8.3***
Family child care (FCC)	4.63	4.19	5.34***	4.5	4.7***	4.6***
Public providers	6.32	5.43	7.74***	5.4	6.2***	6.5***
Weekly price (dollars per week)						
Any provider	164.6	200.4	107.3***	154.2	157.4***	167.7***
Child care centers (CCC)	214.8	252.9	154.1***	205.2	207.8***	217.8***
Family child care (FCC)	144.3	163.0	114.5***	147.3	148.8***	153.5***
Public providers	0.0	0.0	0.0	0.0	0.0	0.0
Total access costs (dollars per week)						
Any provider	172.2	207.5	115.9***	161.4	165.1***	175.4***
Child care centers (CCC)	229.1	261.0	178.1***	220.3	223.0***	231.7***
Family child care (FCC)	152.0	170.0	123.4***	147.3	148.8***	153.5***
Public providers	10.5	9.1	12.9***	9.0	10.3***	10.9***

Note: The confidence intervals are computed using bootstrapping - based on 1000 repetitions (reference: MSA; Below Federal Poverty Line (FPL)): * p<0.1, ** p<0.05, *** p<0.01; Weekly price is based on a weighted average of prices for each age group.

Table 7. Total Access Costs and its Components Based on the E2SFCA Weighted Providers within 20-minutes Driving Time, Minnesota, 2015, by Race and Ethnicity Category

Weighted mean	White	African-American	Hispanic	American Indian	Asian
Driving time (minutes)					
Any provider	4.7	4.1***	4.0***	5.7***	4.2***
Child care centers (CCC)	9.2	4.5***	5.8***	26.4***	4.9***
Family child care (FCC)	4.7	4.1***	4.0***	9.8***	4.2***
Public providers	6.8	4.5***	4.6***	7.7**	5.1***
Weekly price (dollars per week)					
Any providers	158.5	198.7***	169.6***	86.8***	201.3***
Child care centers (CCC)	208.1	250.1***	217.6***	160.2***	256.5***
Family child care (FCC)	141.3	160.6***	146.6***	120.1***	161.9***
Public providers	0.0	0.0	0.0	0.0	0.0
Total access costs (dollars per week)					
Any providers	166.4	205.6***	176.2***	96.3***	208.3***
Child care centers (CCC)	223.5	257.6***	227.3***	204.2***	264.7***
Family child care (FCC)	149.1	167.6***	153.2***	136.3***	168.8***
Public providers	11.3	7.5***	7.7***	12.8**	8.5***

Note: Weekly price is based on a weighted average of prices for each age group. The confidence intervals are computed using bootstrapping - based on 1000 repetitions (reference White): * p<0.1, ** p<0.05, *** p<0.01

Table 8. Adjusted Supply and Cost Measures by Quality Rating, by Region, by Income

	By Region			By Income		
	Statewide	Minneapolis – St Paul metro area	Greater Minnesota	Below FPL	Above FPL & Less than 185%FPL	Above 185% FPL
Slots adjusted for nearby children						
Highly-rated market providers	0.099	0.128	0.054***	0.100	0.097***	0.099
Public providers (highly rated)	0.058	0.031	0.100***	0.081	0.066***	0.051***
All other providers	0.401	0.350	0.482***	0.408	0.398***	0.400***
Share of (adjusted) slots						
Highly-rated market providers	0.177	0.251	0.085***	0.170	0.173***	0.180
Public providers (highly rated)	0.104	0.061	0.157***	0.138	0.118***	0.093***
All other providers	0.719	0.688	0.758***	0.693	0.709***	0.727***
Driving time (minutes)						
Highly-rated market providers	10.5	5.8	18.1***	11.1	11.2	10.3***
Public providers (highly rated)	6.3	5.4	7.7***	5.4	6.2***	6.5***
All other providers	4.6	4.2	5.3***	4.5	4.8***	4.7***
Weekly price (dollars per week)						
Highly-rated market providers	216.7	264.5	140.4***	207.5	209.8***	219.6***
Public providers (highly rated)	0	0	0	0	0	0
All other providers	166.5	195.3	120.6***	161.7	162.1	168.1***
Total access costs (dollars per week)						
Highly-rated market providers	234.3	274.2	170.6***	226.0	228.4***	236.8***
Public providers (highly rated)	10.5	9.1	12.9***	9.0	10.3***	10.9***
All other providers	174.3	202.4	129.4***	169.3	170.0*	175.9***
Quality Premium	1.359	1.372	1.344***	1.343	1.355***	1.363***

Notes: Highly rated market providers are those with a three- or four-star rating and who charge a non-zero price to parents. Public programs include Head Start, Early Head Start and School-Readiness pre-kindergarten programs, which are assigned four-star ratings in Minnesota's quality rating system. All other providers include private (market) providers who either do not participate in the rating system or have a one- or two-star rating. Weekly price is based on a weighted average of prices for each age group. The quality premium is defined as the ratio of average (weekly) total cost (travel costs plus price) at highly-rated providers to all other (non-public) providers within the catchment area. Measures in this table are based on the enhanced 2SFCA method using a 20-minute catchment area and Gaussian distance weight function with beta equal to four. The confidence intervals are computed using bootstrapping - based on 1000 repetitions (reference: MSA; Below Federal Poverty Line (FPL)): * p<0.1, ** p<0.05, *** p<0.01

Table 9. Correlations of quantity measures with cost and quality measures by measure type and region

	Statewide		Minneapolis – St Paul metro area		Greater Minnesota	
	Distance-based (Adj-supply)	Area-based (Slots per child)	Distance-based (Adj-supply)	Area-based (Slots per child)	Distance-based (Adj-supply)	Area-based (Slots per child)
Cost measures						
Weekly Price	-0.08***	-0.06	0.34***	-0.12	0.02***	0.04
Travel Cost	-0.35***	-	-0.38***	-	-0.46***	-
Total Cost	-0.11***	-	0.33***	-	-0.09**	-
Quality measures						
Share Highly-rated	0.08**	-0.02	0.02	0.02	0.23***	-0.05
Share Public	0.18***	0.03	-0.22***	0.00	0.21***	0.03
Share Highly-rated, market	-0.05	-0.04	0.13***	0.02	0.06*	-0.10**

Notes: Unit of analysis is census-tracts (i.e., distance-based family-level measures are aggregated (averaged) up to census-tract for purpose of comparison); The distance-based measures are adjusted supply and adjusted-supply weighted measures of cost and quality shares, as introduced in this paper. The zone-based measures are conventional slots-per-kid, slot-weighted average weekly price and share of slots highly rated by type. The confidence intervals are computed using bootstrapping - based on 1000 repetitions: * $p<0.1$, ** $p<0.05$, *** $p<0.01$

Technical Appendix

Davis, Lee & Sojourner

March 2018

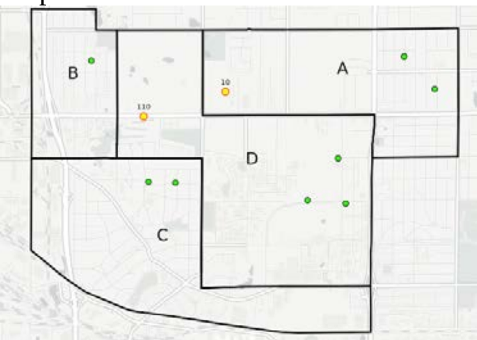
A.1. Illustration of an area-based versus distance-based measure

A.2 Price Imputation

A.3. Deriving Census-block level joint probability using multi-level geographic Census/ACS data

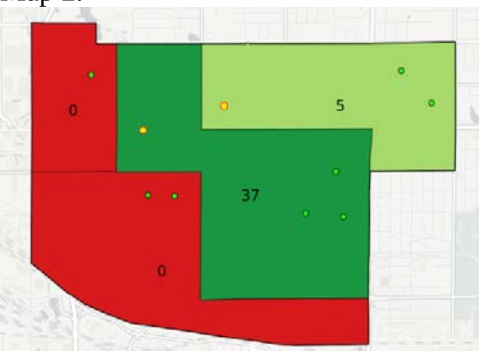
A.1. Illustration of an area-based versus distance-based measure

Map 1.



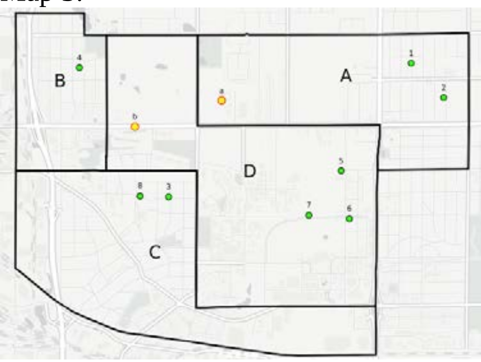
Map 1. Suppose that there are 2 providers (yellow) and 8 children (green) populated in the space within four hypothetical administrative boundaries denoted A, B, C, and D. The number of childcare slots differs by provider. One provider has 110 slots; the other has 10.

Map 2.



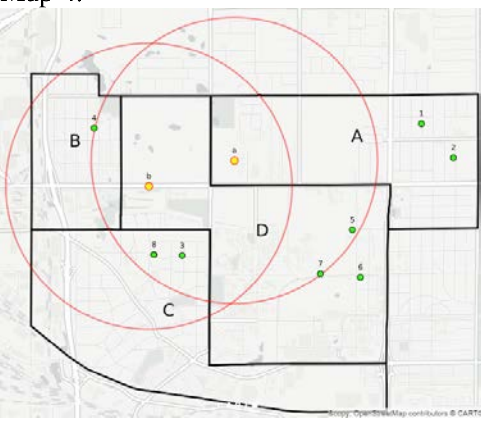
Map 2. A conventional area-based measure of supply is calculated by looking within each administrative area and dividing its number of slots by its number of children. Area A has 5 slots-per-child, B and C each have 0, and D has 37. A choropleth map based on this slots-per-child supply measure shows that B and C are the lowest-access areas (red) and D is the highest-access area (dark green).

Map 3.



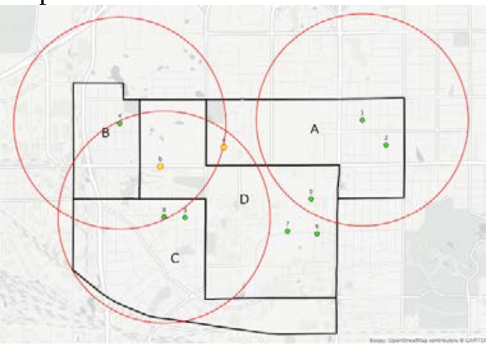
Map 3. Area-based measures can be misleading because of the assumption that slots outside of an area boundary are not available to children in the area, regardless of the actual distance between a provider and child. For example, Child #3, #4 and #8 are each closer to Provider #b than Child #5, #6 and #7.

Map 4.



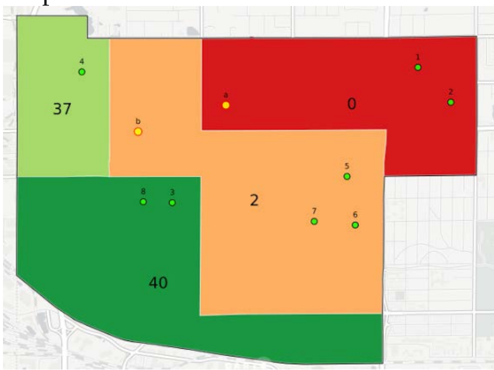
Map 4. Our family-centered adjusted supply focuses on distances rather than administrative boundaries. It uses a two-step process. In the first step, for each provider, the number of nearby children, those within a certain radius of distance or driving time, are counted. In this example, Provider #a has 4 children (Child #3, #5, #7, and #8) nearby and Provider #b has 3 (#3, #4 and #8). The slots-per-nearby-child ratio for each provider therefore is 2.5 (=10/4) for Provider #a, and 37 for Provider #b. Note that drive-time radii will not be perfect circles when using real drive-time data.

Map 5.



Map 5. In the second step, for each child, we identify all nearby providers, then sum up their slots-per-nearby-child ratios as calculated in the first step. For example, child #4 has only provider #b nearby, so adjusted supply measure for child #4 is 37. Adjusted supply for child #1 is 0 because child #1 does not have any providers nearby. Child #8 has both providers nearby so her adjusted supply is 40, the sum of both providers' slots-per-nearby child.

Map 6.



Map 6. For the sake of comparison, this choropleth map is based on the adjusted supply measure. Compared to the area-based choropleth map shown in map 2, one can see that inference drawn from the family-centered measure is opposite the inference from the area-based measure. The lowest-access area is red (area A) and the highest-access areas are green (areas B and C).Whether actual results differ between the two measures will depend on the relative locations of families and providers and the size of the areas.

A.2 Price Imputation

NACCRRAware data contains quarterly reported price information that are collected from child care providers according to the mode in which they charge parents, which can include hourly, daily and weekly rates. Some providers report more than one pricing mode. About 12% of providers report prices in all three options: weekly, daily and hourly. Slightly less than quarter provide only weekly prices and another quarter provide either only hourly or only daily prices. For those providers reporting a weekly price (60%), we use that price in the analysis. For providers who did not report a weekly price, daily or hourly price values were converted to fill in the missing values. Conversions across pricing modes are not consistent across providers. For example, a provider's weekly price is not usually five times the daily price, among those who provide both pricing modes. To convert daily and hourly prices, we first calculated the average week/day, week/hour, day/hour price ratios for providers reporting more than one pricing mode. Averages were calculated for 12 categories based on QRIS rating (unrated, low and high), MSA or non-MSA location, and home-based or center-based provider. These ratios were used to convert the prices to weekly for those providers who did not report a weekly price.

After converting daily and hourly prices to weekly rates, we still have missing price information for about 27.8% of total providers (3,333 of 11,989 providers). Prices for providers missing all price information were imputed using generalized Cliff-Ord spatial econometrics model.

$$\boldsymbol{y} = \lambda \boldsymbol{W}\boldsymbol{y} + \boldsymbol{X}\beta + \boldsymbol{u}$$

$$\boldsymbol{u} = \rho \boldsymbol{W}\boldsymbol{u} + \boldsymbol{\epsilon}$$

where $\boldsymbol{y}$ is the N*1 vector of weekly prices, $\boldsymbol{X}$ is the N*k matrix of explanatory variables which includes last observed Parent Aware rating, MSA status, family child care indicator and level of experience of the childcare provider. $\boldsymbol{W}$ is N*N spatial-weighting matrices that parameterize the distance between neighborhoods (inverse-distance matrices are used for the parameterization for the spatial-weighting matrix using **spmat** command in Stata). $\boldsymbol{u}$ is N*1 spatially correlated residuals and $\boldsymbol{\epsilon}$ N*1 IID error terms. λ and ρ are parameters to be estimated that measures the dependent of y_i on nearby y and the spatial correlation in the error terms, respectively. This procedure delivers unbiased price estimates if prices are missing at random conditional on observables. An alternative approach would be to ignore providers with missing price data. However, this would ignore available information about existing providers' locations and non-price characteristics.

A.3. Deriving Census-block level joint probability using multi-level geographic Census/ACS data

Our goal is to estimate the joint distribution of income (I), race/ethnicity (R) among families with any children under age 5 (C=1), denoted $\Pr(R, I|b, C = 1)$. To accomplish this, we combine data from the ACS 2011-2015 5-year population estimates (ACS 2015) by Census tract (t) and block group (g) with data on Census blocks (b) from the 2010 Census. In comparing our estimates to the data, they will match on:

- Number of families with young children in each 2015 block group.
- Distribution of families with young children across blocks conditional on block group as in 2010.
- Number of families with young children by race in the 2015 block group.
- Distribution of families across blocks conditional on race and block group as in 2010.
- Number of families by detailed, 12-category income conditional on race and census tract as in 2015.

- Distribution of broad, 2-category income conditional on having a young child at the 2015 block group.

Data on the joint distribution of income and race among families with young children is available within each Census tract. The ACS gives:

- Estimated counts of families by race cross two broad income categories cross having at least one child under 5 cell $(\mathrm{R} \times I_2 \times \mathrm{C})$: $\#(\mathrm{R} \times I_2 \times \mathrm{C})_t^{2015}$.
- Estimated counts of families by 12 detailed-income categories (which partition the broad-income categories) not conditioned on R or C, (I_{12}): $\#(I_{12})_t^{2015}$. This implies a tract-specific distribution of detailed-income category conditional on broad-income category, $\Pr(\mathrm{I}_{12}|I_2)_t^{2015}$.
- An assumption that, within tract, the distribution of detailed-income categories conditional on broad-income category does not vary by race and having a young child, $\Pr(\mathrm{I}_{12}|I_2, \mathrm{R}, \mathrm{C}=1)_t^{2015} \equiv \Pr(I_{12}|I_2)_t^{2015}$, implies that we can estimate the tract's distribution of detailed-income category conditional on race, broad-income category and having a young child:

$$\Pr(I_{12}|\mathrm{R}, \mathrm{C}=1, I_2)_t^{2015} = \Pr(\mathrm{I}_{12}|I_2)_t^{2015} \Pr(I_2|\mathrm{R}, \mathrm{C}=1)_t^{2015}$$

That implies an estimate of the joint distribution of detailed income and race among those with young children by tract, $\Pr(I_{12}, \mathrm{R}, \mathrm{C}=1|I_2)_t^{2015}$ or the joint distribution of income and race among parents with child under 5: $\Pr(\mathrm{R}, I_{12}|\mathrm{C}=1, I_2)_t^{2015}$

Each tract contains a handful of block groups and data at the block group level includes an estimated count of families with young children by income in 2 categories: $\#(I_{2,}, g, C=1)_t^{2015}$.

An assumption that among families with a young child in the same broad-income category in the same tract, their distribution across block groups within tract does not differ by race,

$\Pr(\mathrm{g}|I_2, \mathrm{R}, \mathrm{C}=1)_t^{2015} \equiv \Pr(\mathrm{g}|I_2, \mathrm{C}=1)_t^{2015}$, allows us to leverage the block-group data on the distribution of families with young children by income, $\#(I_{2,}, g, C=1)_t^{2015}$, to estimate of the joint distribution of detailed-income category, race, and block group among families with a young child within tract:

$$\Pr(I_{12}, \mathrm{g}, \mathrm{R}, \mathrm{C}=1|I_2)_t^{2015} = \Pr(I_{12}, \mathrm{R}, \mathrm{C}=1|I_2)_t^{2015} \Pr(\mathrm{g}|I_2, \mathrm{R}, \mathrm{C}=1)_t^{2015}$$

$$= \Pr(I_{12}, \mathrm{R}, \mathrm{C}=1|I_2)_t^{2015} \Pr(\mathrm{g}|I_2, \mathrm{C}=1)_t^{2015}$$

This can be expressed as a joint distribution of detailed-income and race among parents with child under 5 in each block group, $\Pr(\mathrm{R}, I_{12}|\mathrm{C}=1, g)_t^{2015}$or as a distribution of detailed-income conditional on race among parents by block group, $\Pr(I_{12}|\mathrm{R}, g, \mathrm{C}=1)_t^{2015}$.

We also have 2010 block-level data. Each block group contains an average of about 30 blocks, so block data pins down the location of population within a block group much more tightly. The 2010 blocks partition the 2015 ACS block groups, which themselves partition the tracts. For each block, we have the 2010 Census count of families by race cross child under 5: $\#(R_, C, g, b)_t^{2010}$. No income (I) data is available at the block level.

We use the spatial and racial distributional information in the 2010 block data to help pin down where within each block group, the population estimated at the 2015 block-group level lives. However, aggregating 2010 blocks up to the block-group level produces different counts and different distributions of race than are estimated in 2015. So we want to use the joint information from 2010 in a way consistent with the 2015 marginals.

In particular, we want to impute block-specific joint distributions of race and income among families with a child under 5 in 2015, $\Pr(\mathrm{R}, \mathrm{I}, \mathrm{b}|g, \mathrm{C}=1)_t^{2015}$, combining available sources of info. To start, assume that within race and block-group, the distribution of population across blocks is the same in 2015 as was observed in 2010:

$$\Pr(b|\mathrm{g},\mathrm{R},\mathrm{C}=1)_t^{2015} \equiv \Pr(b|\mathrm{g},\mathrm{R},\mathrm{C}=1)_t^{2010}$$

This yields an estimate of the joint distribution of race and block among those with a child under 5 in 2015 that is consistent with the observed 2015 block-group conditional marginal distribution of race. We use this to distribute the block-group population estimates down to blocks.

$$\Pr(I_{12},\mathrm{b},\mathrm{R}|\mathrm{g},\mathrm{C}=1)_t^{2015} = \Pr(I_{12},\mathrm{R}|\mathrm{g},\mathrm{C}=1)_t^{2015}\Pr(\mathrm{b}|\mathrm{g},\mathrm{R},\mathrm{C}=1)_t^{2015}$$

$$= \Pr(I_{12},\mathrm{R}|\mathrm{g},\mathrm{C}=1)_t^{2015}\Pr(\mathrm{b}|\mathrm{g},\mathrm{R},\mathrm{C}=1)_t^{2010}$$

The first equality derives from the definition of conditional probability and the second follows from the assumption above. This yields estimates of the number of families with young children and the joint distribution of race and income among them for each block. Dropping the block group, tract, and year notation and focusing only on the block level data now, we have an estimate of the number of families with young children in each block, $\#(C=1|b)$, and their joint distribution of race and income, $\Pr(\mathrm{R},\mathrm{I}|\mathrm{b},\mathrm{C}=1)$.