**Appendix**

**A1. Theoretical Model**

*Substitute and Complement Definitions*

In a competitive market, two goods that are not independent of each other, are either substitutes or complements. Economics provides both formal and conceptual definitions of substitutes and complements. The formal definitions build on the concept of cross-price elasticity of demand, i.e., the relationship between the demand for good 1 and the price of good 2. (The connection between the price and the demand is key in the theory of demand). The cross-price elasticity of demand is defined as the ratio of the incremental percentage change of the demanded quantity of good 1 with respect to the incremental percentage change in the price of good 2, as shown below:

$$e\_{cross 1,2}= ^{\frac{∂Q\_{1}}{Q\_{1}}}/\_{\frac{∂P\_{2}}{P\_{2}}}$$

where Q1 is the demanded quantity of good 1 and P2 is the price of good 2 and $Q\_{1}>0,P\_{2}>0.$ The formal definitions of substitutes and complements correspond to a positive and negative cross-price elasticity, respectively.

 In most Medicaid programs, the enrollees are not facing an actual monetary price when seeking care or are facing a very small, nominal price. It is not uncommon in economics to think of the price as a time cost, when appropriate.

 In the context of studying how Medicaid enrollees use different health care services and what policy implications result from that knowledge, conceptual definitions of substitutes and complements are more meaningful. As the following sections demonstrate, the formal, cross-price elasticity based definitions are not required to identify substitution vs complementarity.

We have identified three relevant conceptual definitions of substitutes in health economics literature:

1. Substitutes are such goods that “using more of one allows use of less of the other in order to achieve the same result.”[1](#_ENREF_1)(p.110)

2. Substitutes in consumption are goods that “satisfy the same wants or provide the same characteristics.”[2](#_ENREF_2)(p.115)

3. A substitute, in the context of health care, “is a benefit or service that can be used instead of another to produce a similar outcome.”[3](#_ENREF_3)(p.499)

After combining and semantically analyzing these definitions and contextualizing them in health care, we use the following definition of substitutes:

*Medical services substitutes are medical services such that one can be used in place of another in order to satisfy a perceived medical care need to a similar extent.*

Similarly, we have identified three conceptual definitions of complements in health economics literature:

1. Complements are such goods or services that “are consumed together, and ‘help each other out’ in producing health.”[1](#_ENREF_1)(p.110)

2. Complements in consumption are goods that “are jointly used for consumption purposes.”[2](#_ENREF_2)(p.114)

3. A complement, in the context of health care, “is a benefit or service that is likely to result in the use of another benefit or service.”[3](#_ENREF_3)(p.499)

After combining and semantically analyzing these definitions and contextualizing them in health care, we use the following definition of substitutes:

*Medical services complements are medical services that either satisfy a perceived medical care need when consumed in combination, or because use of one results in the use of another.*

Consumption of bundles of two goods or services that are not independent is graphically described in consumer choice theory in economics, which forms the basis of our approach. The relationship between the demand for one good and the demand for the other good is represented by an indifference curve. Indifference curves are defined by the loci of points that represent bundles of two goods which produce the same utility for the consumer (i.e. the consumer is indifferent to all points on the curve). Consumers are thought to have a plane of non-intersecting indifference curves, with curves away from the point of origin having increasingly higher utility. Our approach uses the general structure of the indifference curves for substitutes and complements to test whether Medicaid enrollees use the ED and primary care as substitutes or complements, as described in the following sections.

*Substitution Between Primary Care and ED Care*

Figure A1 demonstrates a plane of indifference curves for substitutes. Each indifference curve is a downward sloping curve convex to the origin (for perfect substitutes, it is a linear downward sloping function). The slope of the indifference curve is the rate at which one *is willing* to trade off good 2 for good 1, maintaining the same utility from the consumption of the bundle.



Figure A1. Plane of indifference curves

While all points on one indifference curve produce the same utility from the consumption of the bundle of goods, the optimal point depends on the budget one has. The budget constraint (allowed for purchasing these goods) is a downward-sloping line with the slope $-\frac{P\_{1}}{P\_{2}}$ (ratio of price of good 1 to the price of good 2 with the negative sign). Essentially, the slope of the budget constraint is the rate at which one *can* trade off good 2 for good 1. The optimal point (PC\*, ED\* in Figure A2) is determined by the tangency of the budget constraint line to an indifference curve. Since Medicaid enrollees do not generally face a price, the constraint line can represent a time constraint.

 

Figure A2. Optimal demand for PC and ED care with the time constraint (case of substitutes).

An optimum bundle of PC and ED care is allowed if there is sufficient supply of both goods. A limit on supply can be represented by a vertical line for PC and by a horizontal line for ED care. We assume that supply of ED care is near unrestricted because EDs must accept patients, are always open, and do not require appointments. Because difficulties accessing EDs, such as long waiting times, can affect individuals’ time constraint, we allow for variation around the slope of the time constraint. Primary care supply can be limited, and Medicaid patients likely experience barriers to primary care. If PC supply is sufficient to satisfy demand at the optimum (PC constraint line is to the right of the optimal point – line B1 on Figure A3), then demand for ED care and PC is the same as in Figure A2, i.e. at the optimum (PC\*, ED\*) on indifference curve I\*. If PC supply is not sufficient (PC constraint line to the left of the optimum – line B2 on Figure A3), then the optimum amount of PC is not available, and the demanded bundle of these goods (PC\*\*, ED\*\*) is determined by the intersection of the time constraint line T and the PC constraint line B2. This intersection lies on an indifference curve that is lower than the curve with the unconstrained optimum. This is shown in Figure A3.



Figure A3. Demand for PC and ED care with the time constraint and a PC constraint (case of substitutes).

As the PC supply constraint line moves to the left from the optimum, the amount of available PC decreases, and the intersection with the time constraint T is at lower amounts of PC and higher amounts of ED care.

Demand for ED care therefore is a function of PC supply. As can be seen in Figure A4 (top), when PC supply is sufficient, i.e. to the right of the optimum, demand for ED care is at the optimal amount ED\*, and when PC supply is not sufficient, i.e. to the left of the optimum, demand for ED care is determined by the intersection of the PC constraint line and the time constraint T. Demand for ED care as a function of PC supply is shown in Figure A4 (bottom).



 

Figure A4. Demand for ED care as a function of PC supply. Top: Function derivation. Bottom: Final function (case of substitutes).

*Complementarity Between Primary Care and ED Care*

Consumption of two goods (or services) that are perfect complements is represented in consumer theory by Leontief preference curves, which are L-shaped. The optimal bundle of two complementary goods is given by the corner of the L shape; a higher quantity of one good, i.e. a point on one of the linear segments of a curve, does not generate more utility.

Leontief preference curves are shown in the left-side panel of Figure A5. Since the proportion in which x and y are consumed in this case is fixed regardless of the amount of goods, the function composed of the optimal points (i.e., corners) of all possible preference curves is linear. Our main specification follows this scenario. In additional analyses, we relax the fixed-proportions assumption and allow for the function made up by the equilibrium points to be non-linear as shown in the right-side panel of Figure A5. By the definition of Leontief preference curves, this function is monotonically increasing.

 

Figure A5. Plane of Leontief preference curves (perfect complements). Left: With fixed proportions assumption. Right: Without fixed proportions assumption.

The optimal point (PC\*, ED\*) is determined by y the intersection of the time constraint with the corner of an L-shaped curve, as shown in Figure A6. This optimal bundle of PC and ED care is allowed if there is sufficient supply of both goods.



Figure A6. Optimal demand for PC and ED care with the time constraint (case of complements).

If PC supply is sufficient to satisfy demand at the optimum (PC constraint line is to the right of the optimum – line B1 on Figure A7), then demand for ED care and PC is the same as in Figure A6, i.e. at the optimum (PC\*, ED\*) on Leontief preference curve L\*. If PC supply is not sufficient (PC constraint line to the left of the optimum – line B2 on Figure A7), then the optimal amount of PC is not available, and the demanded bundle of these goods (PC\*\*, ED\*\*) will be determined by the corner of the L-shaped curve, whose vertical segment aligns with PC constraint B2. This Leontief preference curve L\*\* is lower than the curve with the optimum L\*. This is shown in Figure A7.



Figure A7. Demand for PC and ED care with the time constraint and a PC constraint (case of complements).

As PC constraint line moves to the left from the optimum, the amount of available PC decreases, and the bundle is determined by the corner of a lower L-shaped curve, i.e. lower amounts of both PC and ED care.

As in the case of substitutes, demand for ED care is a function of PC supply. As can be seen in Figure A8 (top), when PC supply is sufficient, i.e. to the right of the optimum, demand for ED care is at the optimum amount ED\*. When PC supply is not sufficient, i.e. to the left of the optimum, demand for ED care is determined by the corner of an L-shaped curve whose vertical segment aligns with the PC constraint line. Demand for ED care as a function of PC supply is shown in Figure A8 (bottom). In the linear case, the left spline is a straight, positively sloped line.





Figure A8. Demand for ED care as a function of PC supply. Top: Function derivation. Bottom: Final function (case of complements, nonlinear).

**A2. Estimating Equation**

As shown in Section A1 of this Appendix, we estimate a spline function. Denoting the conditions of the spline function by the indicator functions $⥠\_{X<X^{\*}}\left(X\right)$ and $⥠\_{X\geq X^{\*}}\left(X\right)$, where X\* is PC\* (the optimum amount of PC demanded), we obtain the following:

$$Y=(d+kx^{\*})∙ ⥠\_{X\geq X^{\*}}\left(X\right)+\left(d+kx\right)∙⥠\_{X<X^{\*}}\left(X\right)$$

The above function in the piecewise-defined form can be approximated by the following function, using a logistic cumulative density function $F\left(x\right)=\frac{1}{1+e^{-\frac{x-μ}{s}}}$ , in which µ is replaced by *x\**, as a “switch” between the two splines.

$$Y=(d+kx^{\*})\* \frac{1}{1+e^{-\frac{x-x^{\*}}{s}}}+\left(d+kx\right)\*(1-\frac{1}{1+e^{-\frac{x-x^{\*}}{s}}})$$

Because the “switch” needs to be abrupt, the variance parameter s should be forced to be very small. Arbitrarily choosing *s=*0.001, we obtain the following basic estimating equation:

$$Y\_{cm}=\left(d+kx^{\*}\right)\* \frac{1}{1+e^{-1000\*\left(x\_{cm}-x^{\*}\right)}}+\left(d+kx\_{cm}\right)\*\left(1-\frac{1}{1+e^{-1000\*\left(x\_{cm}-x^{\*}\right)}}\right)+ε\_{cm}$$

where c indexes county, m indexes month, and d, k and x\* are parameters to be estimated with the nonlinear least squares regression method, $Y\_{cm}$ is the number of PCT ED visits per nonelderly Medicaid managed care enrollee, and $x\_{cm}$ is the number of PC providers that contract with Medicaid managed care and accept Medicaid patients.

 Our adjusted models adds a vector of covariates and county fixed effects

$$Y\_{cm}=\left(d+kx^{\*}\right)\* \frac{1}{1+e^{-1000\*\left(x\_{cm}-x^{\*}\right)}}+\left(d+kx\_{cm}\right)\*\left(1-\frac{1}{1+e^{-1000\*\left(x\_{cm}-x^{\*}\right)}}\right)+Z\_{cy}^{'}+φ\_{c}+ε\_{cm}$$

where $Z\_{cy}^{'}$ is a vector of year-varying county covariates and $φ\_{c}$ is county fixed effects.

**A3. Bootstrapping Approach**

Because the universe of ED visits in New York State is aggregated to county-month level in our model, we created 100 bootstrap samples of ED visits, stratified by county. Then ED visits for 100% PCT conditions made by patients 0-64 y.o. and paid by Medicaid managed care were identified. Each sample was then aggregated to county-month level, cleaned and merged with covariates in the same manner as the population (full) data.

Estimating approach was first done on the population model. It was then repeated for the bootstrap samples. Estimates from bootstrap samples were then used to calculate standard errors and p-values.

**A4. Sensitivity Analyses**

Our theoretical framework assumes that the supply of ED is infinite; in sensitivity analyses, we relax this assumption, estimating a three-spline function. This model did not converge to an appropriate solution. Parameters of this model, including the slope coefficient indicating substitution or complementarity, were estimated at the same values as in the main analyses. Even if the underlying function in fact consists of three splines, the two-spline model would underestimate the slope coefficient (smaller coefficient, or less steep left spline), but identification of substitution vs complementarity revealed by hypothesis testing would not be affected.

In our main specification, we estimated an equation with a linear left spline, but in the case of complements, the left spline can be non-linear, as described in the Appendix. In the county subgrouping where we found complementarity (highly urban, during nights and weekends), We estimated a quadratic left spline. In this case, the left spline is estimated to be a decreasing function and our theoretical framework dictates that it must be increasing in the case of complements. We concluded that in this case a non-linear left spline function was not an improvement over the linear left spline function.

**A5. Lists of poorer and wealthier counties (from Table 2)**

All hours:

1. Wealthier county-years (6.0-13.5% population in poverty) with substitution:

Albany 2014-2015; Cayuga 2014-2015; Columbia 2014; Dutchess 2014-2015; Essex 2014-2015; Genessee 2014-2015; Greene 2014; Herkimer 2015; Livingston 2015; Madison 2014-2015; Nassau 2014-2015; Niagara 2014; Ontario 2014-2015; Orange 2014-2015; Putnam 2014-2015; Rensselaer 2014-2015; Saratoga 2014-2015; Schenectady 2014-2015; Schuyler 2015; Suffolk 2014-2015; Tioga 2014-2015; Warren 2014-2015; Washington 2015; Wayne 2014-2015; Westchester 2014-2015; Wyoming 2014-2015.

2. Poorer county-years (25.6-31.5% population in poverty) with complementarity:

Bronx 2014-2015

Night and weekend hours:

1. Wealthier county-years (6.0-12.7% population in poverty) with substitution:

Albany 2015; Cayuga 2014-2015; Columbia 2014; Dutchess 2014-2015; Essex 2014-2015; Genessee 2014; Greene 2014; Hamilton 2014-2015; Herkimer 2015; Madison 2014; Nassau 2014-2015; Ontario 2014-2015; Orange 2015; Putnam 2014-2015; Rensselaer 2015; Saratoga 2014-2015; Schenectady 2015; Schuyler 2015; Suffolk 2014-2015; Tioga 2014-2015; Warren 2015; Wayne 2015; Westchester 2014-2015; Wyoming 2014.

2. Poorer county-years (21.7-31.5% population in poverty) with complementarity:

Bronx 2014-2015; Kings 2014-2015.

Note that these lists do not include county-years that fall into the 95% CI of the estimated cutoff (see explanations in the Notes to Table 2).

Table A1. Summary Statistics, 2012-2013.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | All counties (N=1,261) | Highly urban(N=480) | Moderately urban(N=351) | Rural(N=430) | Below median % in poverty (N=641) | At or above median % in poverty (N=620) |
| Medicaid managed care enrollment count | 62,810(145,594) | 144,860(211,326) | 18,652(13,931) | 7,265(4,040) | 27,104(35,102) | 99,725(197,964) |
| 100% PCT ED visit rate, per 100 enrollees / month | 0.399(0.234) | 0.309(0.129) | 0.488(0.314) | 0.426(0.215) | 0.430(0.274) | 0.367(0.179) |
| 100% PCT ED visit rate, working hours, per 100 enrollees / month | 0.134(0.088) | 0.104(0.050) | 0.162(0.116) | 0.145(0.085) | 0.141(0.100) | 0.127(0.073) |
| 100% PCT ED visit rate, non-working hours, per 100 enrollees / month | 0.265(0.160) | 0.205(0.100) | 0.326(0.207) | 0.281(0.147) | 0.289(0.187) | 0.239(0.121) |
| PC providers accepting Medicaid patients, per 100 enrollees | 0.945(0.468) | 0.962(0.553) | 0.979(0.411) | 0.899(0.400) | 1.110(0.529) | 0.775(0.315) |
| PC physicians accepting Medicaid patients, per 100 enrollees | 0.778(0.383) | 0.851(0.485) | 0.782(0.286) | 0.693(0.297) | 0.908(0.437) | 0.643(0.254) |
| PC APPs accepting Medicaid, per 100 enrollees | 0.168(0.139) | 0.111(0.099) | 0.198(0.164) | 0.206(0.134) | 0.202(0.158) | 0.133(0.104) |

Notes: The table presents means, and standard deviations in parentheses. To obtain annual ED visit rates, the reported monthly ED visit rates should be multiplied by 12. PCT = primary care treatable, ED = emergency department, PC = primary care, APP = advanced practice providers. Physicians include MDs and DOs. APPs include NPs and PAs. Median % poverty is 14.8%.

**Appendix References**

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2. Senterre RE, Neun SP. *Health Economics: Theory, Insights, and Industry Studies*. 5 ed. South-Western Cengage Learning; 2010.

3. Miller M. The role of substitutes in policy analysis: acute care services in state Medicaid programs. *J Health Polit Policy Law*. Fall 1988;13(3):499-524.