Exploring the Implications of Alternative Household- and Person-level Constraints at Multiple Spatial Resolutions in Synthetic Population Generation

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Outline

Introduction

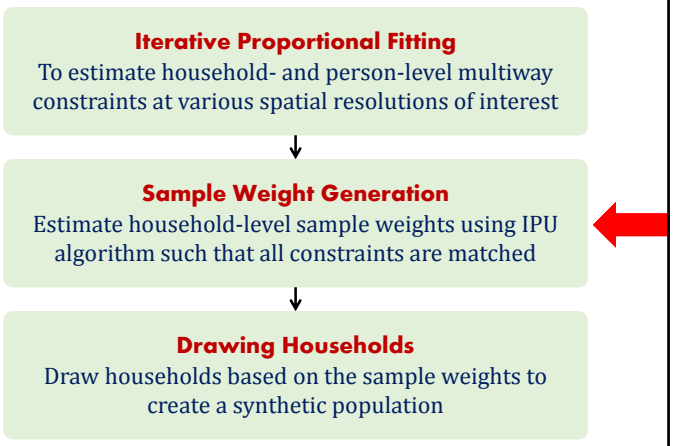
- Disaggregate socio-economic and demographic data for the entire population is a critical input to apply microsimulation models
  - This information is not readily available
- Instead, disaggregate information for a sample of households ("sample data"), and aggregate distributions ("marginal distributions") for the entire population are available
  - Available data are combined to synthesize a population
- Beckman et al (1996) was the earliest synthetic population generator (SPG)
  - Number of SPGs have been developed since
  - Ma and Srinivasan (2015) provide a comprehensive review of generators to date

Multi-level Marginal Distributions

- Agencies often maintain marginal distributions at multiple spatial resolutions
  - For example, control distributions for select variables at the traffic analysis zone (TAZ) level, and additional control distributions for other variables at the county level
- It would be desirable to generate a synthetic population that accounts for all of the information available
- Most of the SPGs in practice today are not able to accommodate multi-level distributions of household and person-level attributes as controls
- An enhanced SPG (PopGen 2.0) that can accommodate multi-level marginal distributions as controls

Overview of PopGen 1.0

- PopGen 1.0 (Ye et al 2009) is able to match given distributions of household- and person-level attributes
- In PopGen 2.0, sample weight generation step is enhanced to accommodate multi-level marginal distributions



Iterative Proportional Updating (IPU): Overview

- The IPU is a heuristic iterative procedure that solves the below optimization problem for estimating household sample weights so that the given constraints are matched

Minimize $\sum_j \left[\frac{\sum_i d_{i,j} w_i - c_j}{c_j}\right]^2$

Subject to $w_i \geq 0$

Where:
i denotes a sample household
j denotes the constraint or population characteristic of interest
$d_{i,j}$ represents the contribution of the sample household i to the population characteristic j
w_i is the weight attributed to sample household i
c_j is the value of the population characteristic j

Iterative Proportional Updating (IPU): Steps

Household ID	Weights	Household Type 1	Household Type 2	Person Type 1	Person Type 2	Person Type 3
1	1	1	0	1	1	1
2	1	1	0	1	0	1
3	1	1	0	2	1	0
4	1	0	1	1	0	2
5	1	0	1	0	2	1
6	1	0	1	1	1	0
7	1	0	1	2	1	2
8	1	0	1	1	1	0
Weighted Sum		3.00	5.00	9.00	7.00	7.00
Constraints		35.00	65.00	91.00	65.00	104.00
δ_b		0.9143	0.9231	0.9011	0.8923	0.9327

Iterative Proportional Updating (IPU): Steps (2)

Iteration 1: Adjustment with respect to Household Type 1 constraint

Household ID	Weights	Household Type 1	Household Type 2	Person Type 1	Person Type 2	Person Type 3	Weights 1
1	1	1	0	1	1	1	11.67
2	1	1	0	1	0	1	11.67
3	1	1	0	2	1	0	11.67
4	1	0	1	1	0	2	1.00
5	1	0	1	0	2	1	1.00
6	1	0	1	1	1	0	1.00
7	1	0	1	2	1	2	1.00
8	1	0	1	1	1	0	1.00
Weighted Sum		3.00	5.00	9.00	7.00	7.00	
Constraints		35.00	65.00	91.00	65.00	104.00	
δ_b		0.9143	0.9231	0.9011	0.8923	0.9327	
Weighted Sum 1		***35.00***	5.00	51.67	28.33	28.33	

Iterative Proportional Updating (IPU): Steps (3)

Iteration 1: Adjustment with respect to Household Type 2 constraint

Household ID	Weights	Household Type 1	Household Type 2	Person Type 1	Person Type 2	Person Type 3	Weights 1	Weights 2
1	1	1	0	1	1	1	11.67	11.67
2	1	1	0	1	0	1	11.67	11.67
3	1	1	0	2	1	0	11.67	11.67
4	1	0	1	1	0	2	1.00	13.00
5	1	0	1	0	2	1	1.00	13.00
6	1	0	1	1	1	0	1.00	13.00
7	1	0	1	2	1	2	1.00	13.00
8	1	0	1	1	1	0	1.00	13.00
Weighted Sum		3.00	5.00	9.00	7.00	7.00		
Constraints		35.00	65.00	91.00	65.00	104.00		
δ_b		0.9143	0.9231	0.9011	0.8923	0.9327		
Weighted Sum 1		***35.00***	5.00	51.67	28.33	28.33		
Weighted Sum 2		35.00	***65.00***	111.67	88.33	88.33		

Iterative Proportional Updating (IPU): Steps (4)

Iteration 1: Adjustment with respect to Person Type 1 constraint

Household ID	Weights	Household Type 1	Household Type 2	Person Type 1	Person Type 2	Person Type 3	Weights 1	Weights 2	Weights 3
1	1	1	0	1	1	1	11.67	11.67	9.51
2	1	1	0	1	0	1	11.67	11.67	9.51
3	1	1	0	2	1	0	11.67	11.67	9.51
4	1	0	1	1	0	2	1.00	13.00	10.59
5	1	0	1	0	2	1	1.00	13.00	13.00
6	1	0	1	1	1	0	1.00	13.00	10.59
7	1	0	1	2	1	2	1.00	13.00	10.59
8	1	0	1	1	1	0	1.00	13.00	10.59
Weighted Sum		3.00	5.00	9.00	7.00	7.00			
Constraints		35.00	65.00	91.00	65.00	104.00			
δ_b		0.9143	0.9231	0.9011	0.8923	0.9327			
Weighted Sum 1		***35.00***	5.00	51.67	28.33	28.33			
Weighted Sum 2		35.00	***65.00***	111.67	88.33	88.33			
Weighted Sum 3		28.52	55.38	***91.00***	76.80	74.39			

Iterative Proportional Updating (IPU): Steps (5)

Iteration 1: Adjustment with respect to Person Type 2 constraint

Household ID	Weights	Household Type 1	Household Type 2	Person Type 1	Person Type 2	Person Type 3	Weights 1	Weights 2	Weights 3	Weights 4
1	1	1	0	1	1	1	11.67	11.67	9.51	8.05
2	1	1	0	1	0	1	11.67	11.67	9.51	9.51
3	1	1	0	2	1	0	11.67	11.67	9.51	8.05
4	1	0	1	1	0	2	1.00	13.00	10.59	10.59
5	1	0	1	0	2	1	1.00	13.00	13.00	11.00
6	1	0	1	1	1	0	1.00	13.00	10.59	8.97
7	1	0	1	2	1	2	1.00	13.00	10.59	8.97
8	1	0	1	1	1	0	1.00	13.00	10.59	8.97
Weighted Sum		3.00	5.00	9.00	7.00	7.00				
Constraints		35.00	65.00	91.00	65.00	104.00				
δ_b		0.9143	0.9231	0.9011	0.8923	0.9327				
Weighted Sum 1		***35.00***	5.00	51.67	28.33	28.33				
Weighted Sum 2		35.00	***65.00***	111.67	88.33	88.33				
Weighted Sum 3		28.52	55.38	***91.00***	76.80	74.39				
Weighted Sum 4		25.60	48.50	80.11	***65.00***	67.68				

Iterative Proportional Updating (IPU): Steps (6)

Iteration 1: Adjustment with respect to Person Type 3 constraint

Household ID	Weights	Household Type 1	Household Type 2	Person Type 1	Person Type 2	Person Type 3	Weights 1	Weights 2	Weights 3	Weights 4	Weights 5
1	1	1	0	1	1	1	11.67	11.67	9.51	8.05	12.37
2	1	1	0	1	0	1	11.67	11.67	9.51	9.51	14.61
3	1	1	0	2	1	0	11.67	11.67	9.51	8.05	8.05
4	1	0	1	1	0	2	1.00	13.00	10.59	10.59	16.28
5	1	0	1	0	2	1	1.00	13.00	13.00	11.00	16.91
6	1	0	1	1	1	0	1.00	13.00	10.59	8.97	8.97
7	1	0	1	2	1	2	1.00	13.00	10.59	8.97	13.78
8	1	0	1	1	1	0	1.00	13.00	10.59	8.97	8.97
Weighted Sum		3.00	5.00	9.00	7.00	7.00					
Constraints		35.00	65.00	91.00	65.00	104.00					
δ_b		0.9143	0.9231	0.9011	0.8923	0.9327					
Weighted Sum 1		***35.00***	5.00	51.67	28.33	28.33					
Weighted Sum 2		35.00	***65.00***	111.67	88.33	88.33					
Weighted Sum 3		28.52	55.38	***91.00***	76.80	74.39					
Weighted Sum 4		25.60	48.50	80.11	***65.00***	67.68					
Weighted Sum 5		35.02	64.90	104.84	85.94	***104.00***					

Iterative Proportional Updating (IPU): Steps (7)

Weights at the end of 638 iterations

Household ID	Weights	Household Type 1	Household Type 2	Person Type 1	Person Type 2	Person Type 3	Final Weights
1	1	1	0	1	1	1	1.36
2	1	1	0	1	0	1	25.66
3	1	1	0	2	1	0	7.98
4	1	0	1	1	0	2	27.79
5	1	0	1	0	2	1	18.45
6	1	0	1	1	1	0	8.64
7	1	0	1	2	1	2	1.47
8	1	0	1	1	1	0	8.64
Weighted Sum		35.00	65.00	91.00	65.00	104.00	
Constraints		35.00	65.00	91.00	65.00	104.00	
δ_b		0.0000	0.0000	0.0000	0.0000	0.0000	

PopGen 1.0: Multi-level Marginal Distributions

- Weights are estimated for each geographic unit independently such that household- and person-level constraints are satisfied
  - As a result, PopGen 1.0 is not capable of accounting multi-level controls
- In PopGen 2.0, the IPU procedure is extended so that weights are generated for all geographic units simultaneously such that multi-level marginal distributions are matched

Illustration of Extended IPU Methodology

- Consider a region with two geographies (Geo 1 and Geo 2)
- The first level of controls is at the region level (say a county) and second level of controls is at the geographic unit level (say a TAZ)

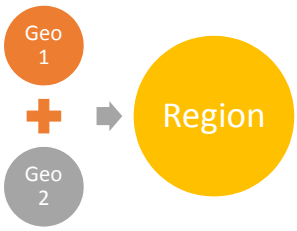
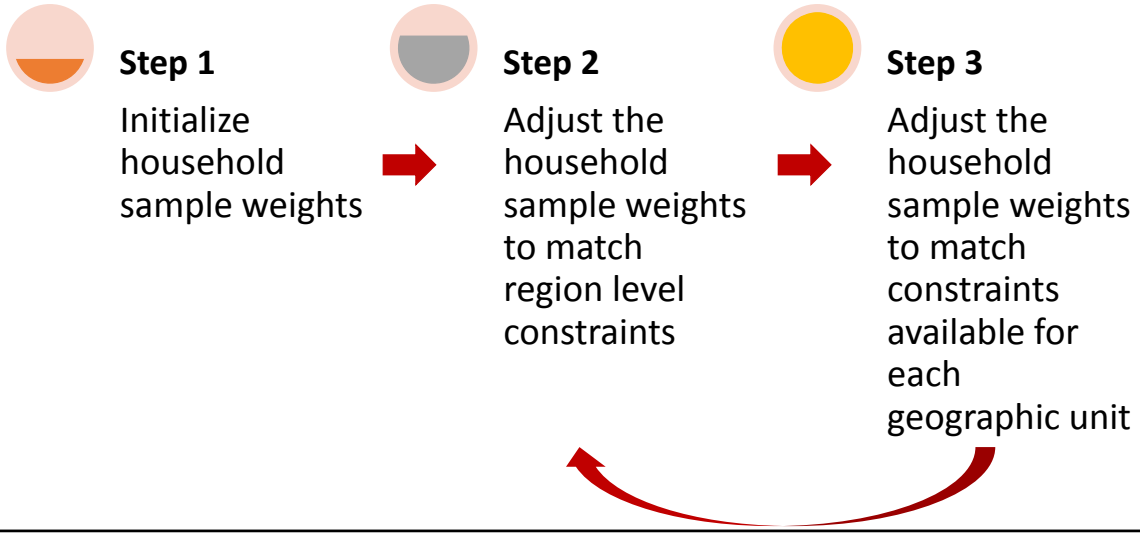


Illustration of Extended IPU Methodology (2)



Iteration 1, Step 1: Initial Household Sample Weight

			Region HH Type			HH Type		Person Type		
For first geographic unit (Geo 1)	hid	weight	1	2	3	1	2	1	2	3
	1	1	0	0	1	1	0	1	1	1
	2	1	1	0	0	1	0	1	0	1
	3	1	0	1	0	1	0	2	1	0
	4	1	1	0	0	0	1	1	0	2
	5	1	0	1	0	0	1	0	2	1
	6	1	0	0	1	0	1	1	1	0
	7	1	0	1	0	0	1	2	1	2
	8	1	0	0	1	0	1	1	2	0
		Geo 1			Weighted Sum	3	5	9	8	7
					Constraint	46	51	92	88	84
					δ	0.94	0.90	0.90	0.91	0.92
For second geographic unit (Geo 2)	hid	weight	1	2	3	1	2	1	2	3
	1	1	0	0	1	1	0	1	1	1
	2	1	1	0	0	1	0	1	0	1
	3	1	0	1	0	1	0	2	1	0
	4	1	1	0	0	0	1	1	0	2
	5	1	0	1	0	0	1	0	2	1
	6	1	0	0	1	0	1	1	1	0
	7	1	0	1	0	0	1	2	1	2
	8	1	0	0	1	0	1	1	2	0
		Geo 2			Weighted Sum	3	5	9	8	7
					Constraint	33	99	138	122	104
					δ	0.91	0.95	0.94	0.93	0.93
Match in constraints for Region		Weighted Sum	4.0	6.0	6.0					
		Constraint	86	61	82					
		δ	0.953	0.902	0.927					

Iteration 1, Step 2: Adjust weights to match region level constraints

			Region HH Type			HH Type		Person Type		
For first geographic unit (Geo 1)	hid	weight	1	2	3	1	2	1	2	3
	1	13.67	0	0	1	1	0	1	1	1
	2	21.50	1	0	0	1	0	1	0	1
	3	10.17	0	1	0	1	0	2	1	0
	4	21.50	1	0	0	0	1	1	0	2
	5	10.17	0	1	0	0	1	0	2	1
	6	13.67	0	0	1	0	1	1	1	0
	7	10.17	0	1	0	0	1	2	1	2
	8	13.67	0	0	1	0	1	1	2	0
		Geo 1			Weighted Sum	45.33	69.17	124.67	95.33	108.67
					Constraint	46	51	92	88	84
					δ	0.01	0.36	0.36	0.08	0.29
For second geographic unit (Geo 2)	hid	weight	1	2	3	1	2	1	2	3
	1	13.67	0	0	1	1	0	1	1	1
	2	21.50	1	0	0	1	0	1	0	1
	3	10.17	0	1	0	1	0	2	1	0
	4	21.50	1	0	0	0	1	1	0	2
	5	10.17	0	1	0	0	1	0	2	1
	6	13.67	0	0	1	0	1	1	1	0
	7	10.17	0	1	0	0	1	2	1	2
	8	13.67	0	0	1	0	1	1	2	0
		Geo 2			Weighted Sum	45.33	69.17	124.67	95.33	108.67
					Constraint	33	99	138	122	104
					δ	0.37	0.30	0.10	0.22	0.05
Match in constraints for Region		Weighted Sum	86.0	61.0	82.0					
		Constraint	86	61	82					
		δ	0.000	0.000	0.000					

Iteration 1, Step 3: Adjust weights to match geography level constraints

			Region HH Type			HH Type		Person Type		
For first geographic unit (Geo 1)	hid	weight	1	2	3	1	2	1	2	3
	1	13.87	0	0	1	1	0	1	1	1
	2	21.82	1	0	0	1	0	1	0	1
	3	10.32	0	1	0	1	0	2	1	0
	4	21.50	1	0	0	0	1	1	0	2
	5	10.17	0	1	0	0	1	0	2	1
	6	13.67	0	0	1	0	1	1	1	0
	7	10.17	0	1	0	0	1	2	1	2
	8	13.67	0	0	1	0	1	1	2	0
	Geo 1				Weighted Sum	44.120	52.643	106.869	86.249	84.000
					Constraint	46	51	92	88	84
					δ	0.041	0.032	0.162	0.020	0.000
For second geographic unit (Geo 2)	hid	weight	1	2	3	1	2	1	2	3
	1	13.67	0	0	1	1	0	1	1	1
	2	21.50	1	0	0	1	0	1	0	1
	3	10.17	0	1	0	1	0	2	1	0
	4	21.50	1	0	0	0	1	1	0	2
	5	10.17	0	1	0	0	1	0	2	1
	6	13.67	0	0	1	0	1	1	1	0
	7	10.17	0	1	0	0	1	2	1	2
	8	13.67	0	0	1	0	1	1	2	0
	Geo 2				Weighted Sum	27.844	87.550	122.800	110.679	104.000
					Constraint	33	99	138	122	104
					δ	0.156	0.116	0.110	0.093	0.000
Match in constraints for Region		Weighted Sum	67.444	59.825	84.888					
		Constraint	86	61	82					
		δ	0.216	0.019	0.035					

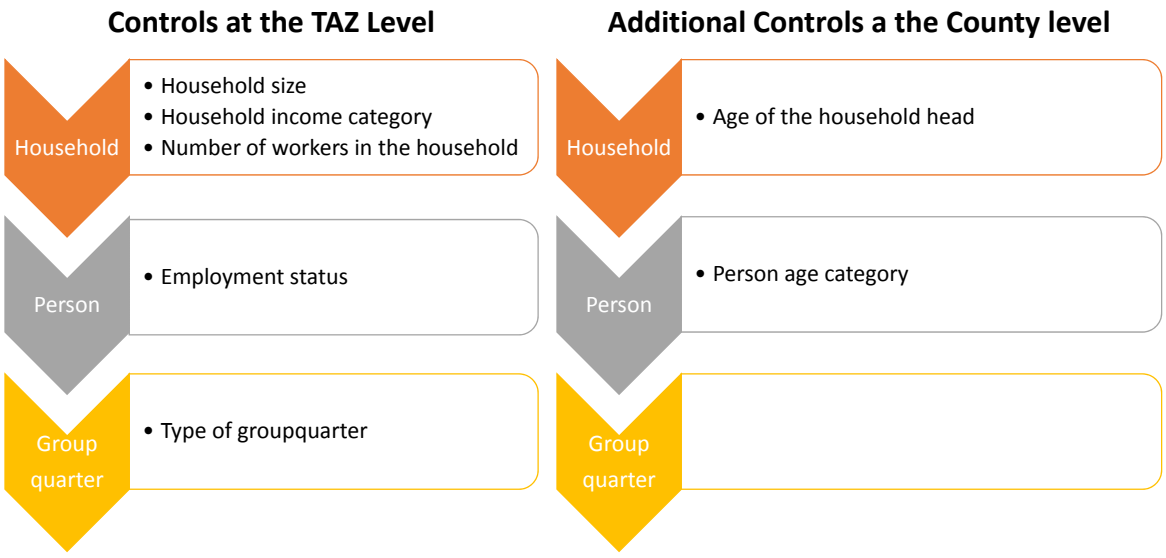
Adjusted weights at the end of 1000 Iterations

			Region HH Type			HH Type		Person Type		
For first geographic unit (Geo 1)	hid	weight	1	2	3	1	2	1	2	3
	1	8.33	0	0	1	1	0	1	1	1
	2	25.71	1	0	0	1	0	1	0	1
	3	12.19	0	1	0	1	0	2	1	0
	4	12.19	1	0	0	0	1	1	0	2
	5	20.02	0	1	0	0	1	0	2	1
	6	8.22	0	0	1	0	1	1	1	0
	7	2.78	0	1	0	0	1	2	1	2
	8	8.22	0	0	1	0	1	1	2	0
	Geo 1				Weighted Sum	46.23	51.43	92.60	88.00	84.00
					Constraint	46	51	92	88	84
					δ	0.005	0.009	0.007	0.000	0.000
For second geographic unit (Geo 2)	hid	weight	1	2	3	1	2	1	2	3
	1	4.46	0	0	1	1	0	1	1	1
	2	17.71	1	0	0	1	0	1	0	1
	3	11.00	0	1	0	1	0	2	1	0
	4	30.39	1	0	0	0	1	1	0	2
	5	10.31	0	1	0	0	1	0	2	1
	6	26.85	0	0	1	0	1	1	1	0
	7	5.38	0	1	0	0	1	2	1	2
	8	26.85	0	0	1	0	1	1	2	0
	Geo 2				Weighted Sum	33.17	99.77	139.00	122.00	104.00
					Constraint	33	99	138	122	104
					δ	0.005	0.008	0.007	0.000	0.000
Match in constraints for Region		Weighted Sum	86.0	61.7	82.9					
		Constraint	86.0	61.0	82.0					
		δ	0.000	0.011	0.011					

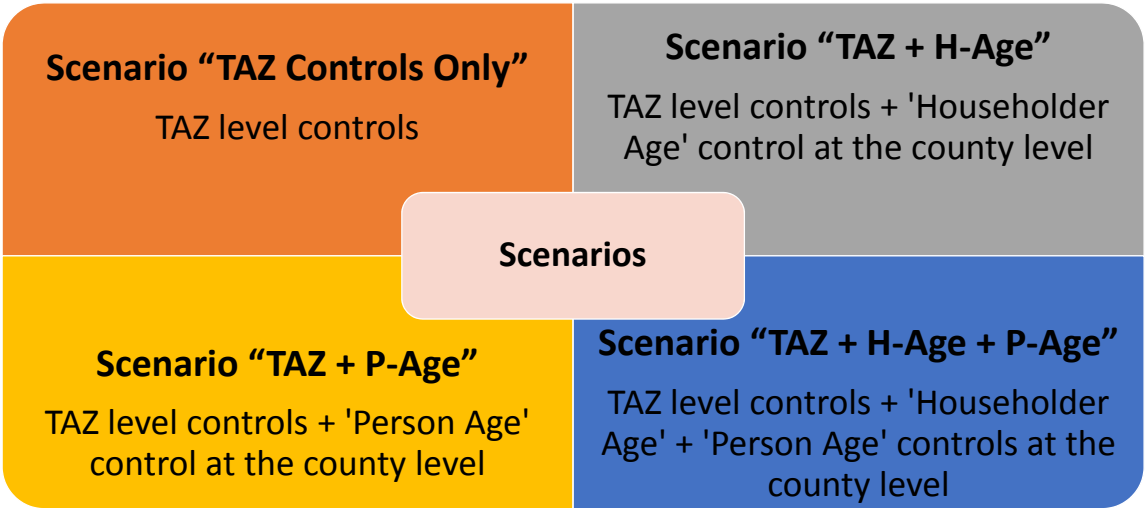
Case Study

- Model area: Baltimore Metropolitan Council (BMC) region
  - Households: 1,801,162
  - Persons: 4,793,980
  - Groupquarters: 104,522
- Marginal distributions are available at TAZ and County levels
- Generate a synthetic population utilizing the extended IPU procedure

Case Study: Control Variables



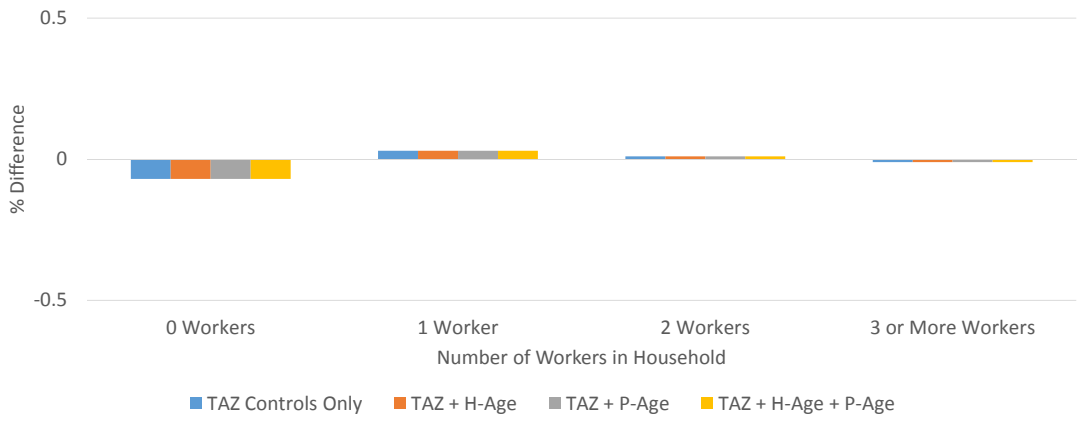
Case Study: Scenarios



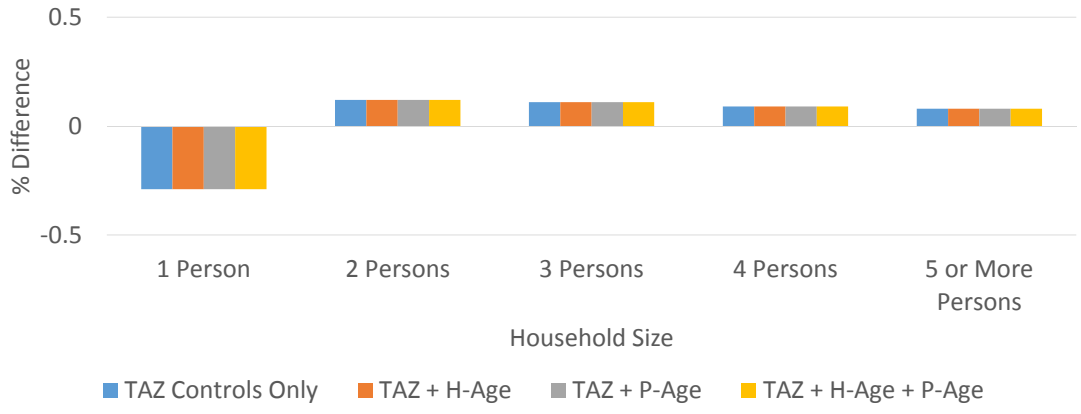
Results: Aggregate Comparisons

Scenario	Household Total			Person Total			Groupquarter Total		
	Given	Synthesized	% Diff	Given	Synthesized	% Diff	Given	Synthesized	% Diff
TAZ Controls Only	1801191	1801191	0.0%	4793980	4790075	-0.1%	104522	104522	0.0%
TAZ + H-Age	1801191	1801191	0.0%	4793980	4795380	0.0%	104522	104522	0.0%
TAZ + P-Age	1801191	1801191	0.0%	4793980	4722872	-1.5%	104522	104522	0.0%
TAZ + H-Age + P-Age	1801191	1801191	0.0%	4793980	4721624	-1.5%	104522	104522	0.0%

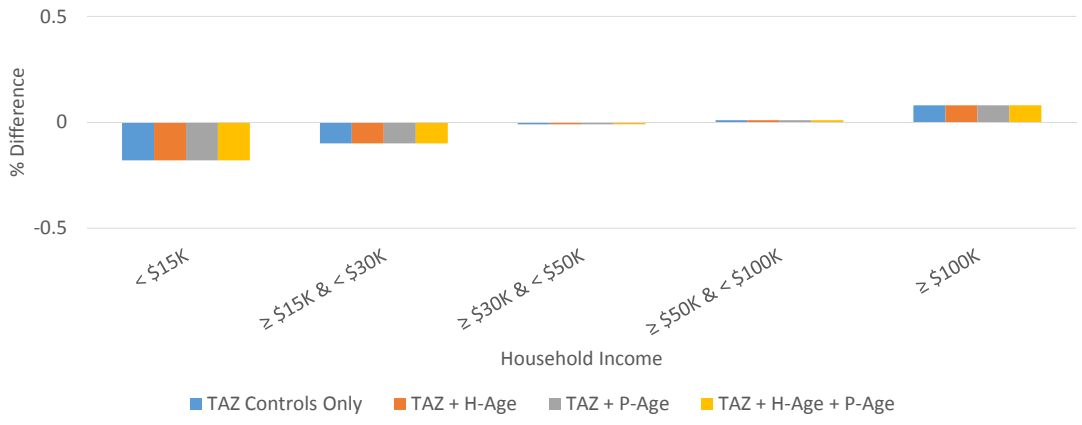
Results: Comparison of Worker Count Distribution



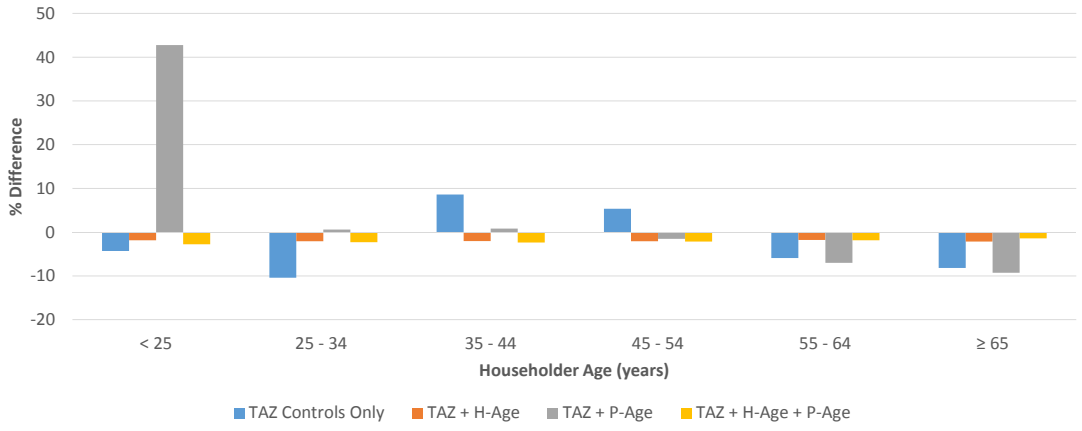
Results: Comparison of Household Size Distribution



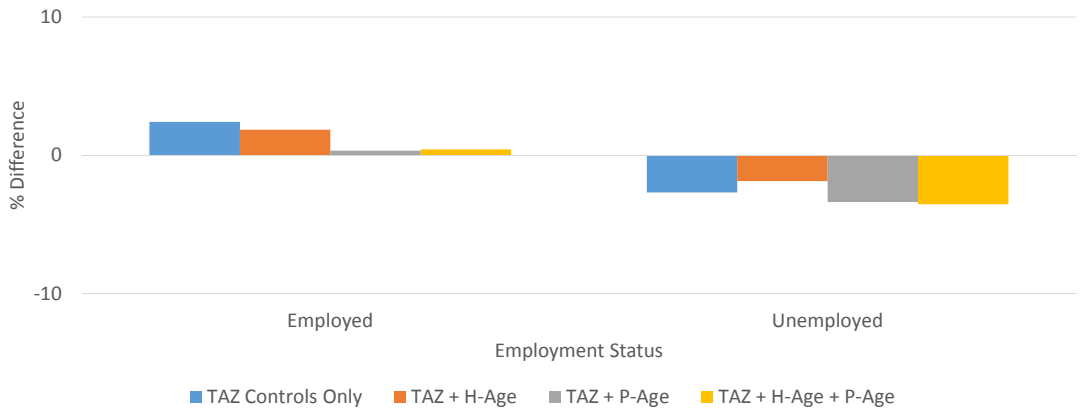
Results: Comparison of Household Income Distribution



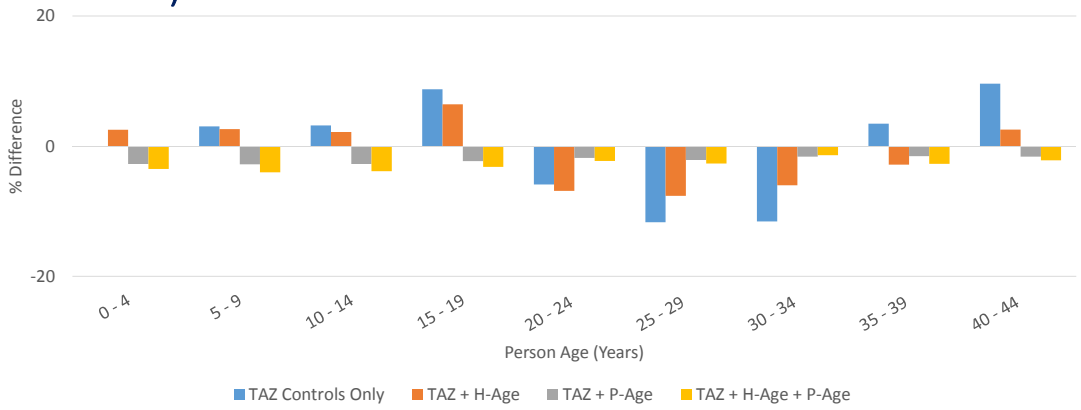
Results: Comparison of Householder Age Distribution
(county-level control)



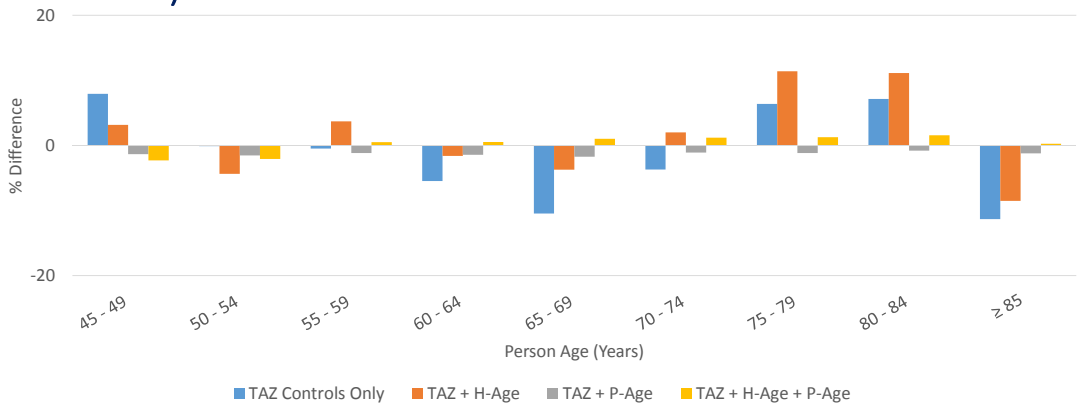
Results: Comparison of Employment Status Distribution



Results: Comparison of Person Age Distribution (county-level control)



Results: Comparison of Person Age Distribution (county-level control)



County Level Comparison of Fit Due to Additional Control: Householder Age

Scenario	County ID	Householder Age		Scenario	County ID	Householder Age	
		% Deviation Across Categories				% Deviation Across Categories	
		Min	Max			Min	Max
TAZ Controls Only	3	-10.08	9.50	TAZ + H-Age	3	-3.06	-2.01
	5	-10.03	9.11		5	-2.31	-1.14
	13	-12.68	58.81		13	0.13	4.32
TAZ + P-Age	3	-14.56	68.53	TAZ + H-Age + P-Age	3	-3.52	-1.37
	5	-8.67	43.22		5	-3.37	-1.32
	13	-9.19	161.83		13	1.33	4.37

County Level Comparison of Fit Due to Additional Control: Person Age

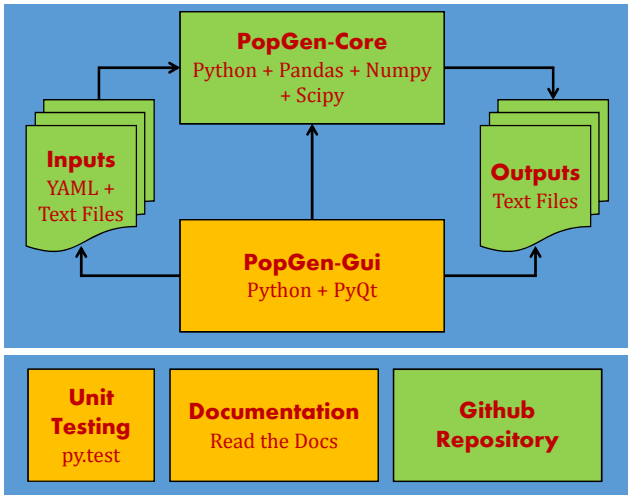
Scenario	County ID	Person Age		Scenario	County ID	Person Age	
		% Deviation Across Categories				% Deviation Across Categories	
		Min	Max			Min	Max
TAZ Controls Only	3	-9.89	17.05	TAZ + H-Age	3	-4.94	24.21
	5	-32.11	13.10		5	-28.18	12.31
	13	-14.38	30.04		13	-8.09	19.75
TAZ + P-Age	3	-1.77	1.66	TAZ + H-Age + P-Age	3	-3.38	5.83
	5	-1.74	0.14		5	-3.34	2.47
	13	-3.08	1.72		13	-5.25	6.97

Conclusions

- PopGen 2.0 is able to accommodate controls at multiple spatial resolutions simultaneously
- Highly efficient algorithm facilitates generation of representative synthetic population
- There is a considerable improvement in fit when additional controls are utilized
- More variables will not necessarily improve the quality of synthesis as much as more unique variables will

PopGen 2.0

- The extended IPU procedure has been incorporated into a completely new implementation named PopGen 2.0
- Beta release available https://github.com/foss-transportationmodeling/popgen/releases
- More information: http://www.simtravel.org/popgen.html



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Questions?