SEIGMA

SOCIAL AND ECONOMIC IMPACTS OF GAMBLING IN MASSACHUSETTS

UNIVERSITY OF MASSACHUSETTS SCHOOL OF PUBLIC HEALTH AND HEALTH SCIENCES

Measuring the Economic Effects of Casinos on Local Areas:

Applying a Community Comparison Matching Method

11/5/2014

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Introduction

The purpose of this paper is to provide an overview of community matching, one of the methods we will use to analyze the economic impacts of gaming venues in Massachusetts.[1] Community matching involves selecting a group of communities that are economically and demographically similar to the casino host communities in Massachusetts. Once casinos open in Massachusetts, comparisons of data trends between the casino host communities and their matched control communities will provide a relative assessment of the impacts of casinos over time. To be clear, community matching is not the only method we will use to conduct our economic impact analysis. Rather, it is intended to complement our other methods and enhance our overall assessment of the economic impacts of casinos. While a brief description of our methods is outlined below, the purpose and focus of this paper is to provide detail about the community matching method.[2]

The Spread of Casino Gambling

Casino gambling in the United States includes commercially operated casinos, Class III Indian casinos and racetracks with co-located slot machines or video lottery terminals. Before 1990, casino gambling was legal and operating in two states: Nevada and New Jersey. In November 2011, legislation was passed permitting casinos to be introduced to Massachusetts for the first time. Three casino licenses are available in Massachusetts with one license allocated in each of three regions of the state along with a single license for a slots parlor with no geographic restriction as to its location. When its first casino opens in 2015, Massachusetts will be the 36th state with legal operating casinos. This is a remarkable transformation in a twenty five year span, particularly compared to the nearly five-decade span between 1931, when Nevada legalized casinos, and 1978, when the first casino outside Nevada opened in Atlantic City, New Jersey.

This expansion of casino gambling has been controversial with much of the debate centered on the social and economic impacts of casino gambling. This debate is ongoing, in part because measuring the impacts of a casino is challenging. The nature of that challenge is described below along with our chosen methods for evaluating the economic impacts of casino introduction.

[1] In this analysis, gaming venues are defined as commercial casinos, Class III Indian casinos, or racetracks with slot machines and video lottery terminals.

[2] The broader SEIGMA project will provide a comprehensive review of social and economic impacts related to the introduction of casino gambling in Massachusetts. For a detailed discussion about the research plan, see *Report on the Research Agenda of the Massachusetts Gaming Commission*. December 5, 2013. http://www.umass.edu/seigma/sites/default/files/Report-on-the-MGC-Research-Agenda.pdf

Estimating the Economic Impacts of Casinos

The most fundamental challenge in estimating the economic impacts of a casino is the inability to know what would have occurred had the casino never opened. In academic circles, this is referred to as the counterfactual. Ideally we would compare the same community or area in two different settings: one where the casino opens, the other where it does not. But clearly, we can only observe one of these outcomes.[3] While we can observe what happens to, for example, the unemployment rate after a casino opens, we cannot really know what the unemployment rate would have been had the casino not opened. Instead, we have to compare the unemployment rate in the community with the new casino with some other unemployment rate which we think is similar to what would have occurred if the casino was not built. The impact on unemployment is the difference between the observed rate in the casino community and the rate from some other similar community.

There is no single perfect method to estimate the economic impacts that a casino has on a community or region.[4] Consequently, we plan to use several different techniques to assess the impacts. While each technique has different limitations, taken together, the results of each method will help to increase confidence in our conclusions. Below, we describe the different techniques we plan to use to assess the economic impacts of casinos in Massachusetts.

Economic Impact Assessment Methods

To assess the economic impacts of casinos in Massachusetts we will be employing multiple approaches organized around two overarching methods: analyzing secondary data for host communities and regions; and primary data collection and economic impact modeling.
The most straightforward approach to assessing change is simply a before and after comparison for the host community. This extends to comparing outcomes after the casino opened with their historical trend. This approach is limited by the inability to distinguish changes resulting from the casino introduction from other changes, such as those resulting from state, regional, or national trends.

[3] This is what Holland (1986) refers to as the fundamental problem of causal inference and highlights one reason why measuring the impacts of casino gambling is challenging.
[4] We will examine regional impacts as part of our broader analysis but our matching analysis will primarily focus on the host communities.

Table 1: Economic analysis—two complementary approaches

I. Analysis of Secondary Data		*Examples*
	1) Compare the casino host community before and after the casino's introduction, using a wide mix of secondary data.	*Compare the unemployment rate prior to the casino opening versus after.*
	2) Compare the casino host community after casino introduction with estimates based on its pre-casino trend.	*Compare the unemployment rate prior to the casino opening versus after.*
	3) Compare the casino host community with Massachusetts and the U.S.	*Compare annual growth in median household income in the host community with annual growth in median household income in Massachusetts as a whole over the same time period.*
	4) Compare the casino host community with other non-casino communities that are economically and demographically similar.	*Compare changes in the unemployment rate in the host community with changes in the unemployment rate in economically and demographically matched control communities over the same time period.*
II. Analysis of Primary Data and Economic Impact Modeling		
	1) Analyze primary data on casino related activity gathered directly from casinos and communities.	*The number of employees hired by the casino.*
	2) Estimate the direct and total economic impact (including multiplier and dynamic effects) of casinos using a Regional Economic Model, Inc., (REMI) model.	*Compare changes in employment growth in host community with employment growth estimated using primary data as input to the REMI model.*

Note: For detailed discussion about the economic research plan see *Report on the Research Agenda of the Massachusetts Gaming Commission*. December 5, 2013. pp 36-44. http://www.umass.edu/seigma/sites/default/files/Report-on-the-MGC-Research-Agenda.pdf

To better account for changes in state or regional economic conditions, such as growth in employment resulting from economic recovery, difference-in-differences calculations can compare economic conditions in the casino host communities with those same conditions in Massachusetts and the U.S. Specifically, changes in economic conditions (e.g., unemployment rate, median household income) before and after casino introduction in the host community will be compared with changes in those conditions in Massachusetts and the U.S. over the same time period.[5]

[5] See Appendix A for an explanation of how difference-in-differences are calculated.

Another method of estimating the economic impact of casinos that we will apply in this study is to compare casino communities with matched non-casino communities. The matched non-casino communities have been chosen based on their economic and demographic similarity to the casino communities prior to casino introduction. Comparison of casino communities to matched non-casino communities has advantages over state and national comparisons because the matched communities are more similar to the casino communities. For example, a casino community may have lower income, higher unemployment or slower job growth than Massachusetts as a whole.[6] The use of matched control communities is a method of accounting for differences in host communities by choosing other non-casino communities that are economically and demographically similar (e.g. have similar unemployment and job growth). Matching is a well-established and widely accepted method used to analyze the economic impact of major economic, policy, or program changes, such as the opening of a new factory, the introduction of educational programs or job search assistance programs, or, in our case, the opening of a casino.[7]

These matched control communities serve as the comparison group for the casino host communities. Choosing control communities that are economically and demographically similar to the host communities prior to casino introduction enables us to better judge the economic impact of casinos by comparing the host communities with the control communities. Intuitively, the matched control communities enable us to estimate of what would have occurred in the host community had the casino not opened. This method is not perfect, of course, since communities may differ on factors that we cannot measure (e.g., attitudes toward gambling) and other factors may change (e.g., unrelated large businesses may open or close). However, this approach is a valuable method to estimate economic impacts due specifically to the introduction of casinos. Nevertheless, it will only be one component of our overall analysis and will be considered equally alongside our other estimation strategies.

While matching communities is a generally accepted approach, there are many challenges to applying a matching community comparison method to help estimate the economic impacts of casino introduction in Massachusetts. A description of these challenges and how they affect our methods of analysis are described below.

Determining the Geography for Analysis

Host communities for the Massachusetts Gaming Commission are well-defined in Chapter 23K of the General Laws. A host community is "a municipality in which a gaming establishment is

[6] This is known as selection bias and occurs when a treatment, in this case casino introduction, is not randomly assigned.

[7] For examples, see Rubin (1974), Rosenbaum and Rubin (1985), Heckman, Ichimura, and Todd (1997), Imbens and Wooldridge (2009).

located or in which an applicant has proposed locating a gaming establishment."[8] In spite of this clear geographic delineation, we must still confirm the most appropriate geographic unit for economic analysis. Should it be the city or town where the casino is located, the county where the casino is located, or based on some other definition, such as distance from the casino? Many academic studies investigating the economic impacts of casinos are conducted at the county level. However, this tends to be because data at more aggregate levels, such as the county or the state, is easier to obtain than data at the town/city level which tends to be more limited and difficult to obtain.

The question of the geographic scope for the analysis is important as economic impacts will vary depending on the definition selected. Clearly, the impact that the casino has on the host city or town is important and should be measured whenever possible. However, the impacts of a casino are likely to spread beyond city and town borders. How far beyond is not known.

The availability and reliability of data are key practical determinants in the geographic area to be analyzed. Obtaining economic data for geographic units other than well-defined city and county boundaries is not possible. However, analysis at the county level in Massachusetts is clearly too broad to illustrate the most immediate, local impacts. Therefore, we have decided to conduct our analysis at the city/town level (while other secondary data measures and the REMI modeling will include regional analysis).[9]

Selecting Matched Control Jurisdictions

Massachusetts will have up to three casinos and one slots parlor, for a potential total of four host communities. To develop a customized, academically sound matching method for Massachusetts host communities, we have focused on selecting the most appropriate matched control communities to use for comparison with the host communities. The most appropriate control community is one that closely resembles the host community prior to the casino opening. Choosing the control community involves several decisions, including the matching method to be employed, characteristics chosen to perform matching, and the number of control communities.

There are two basic methods used to select matched control communities: covariate matching and propensity score matching. Without going into the technical details, having only four host communities prohibits the use of propensity score matching.[10] As a result, we will use covariate

[8] Definitions related to *the Act Establishing Expanded Gaming in The Commonwealth* are found in Section 2 of Chapter 23K of the Massachusetts General Laws, See: https://malegislature.gov/Laws/GeneralLaws/PartI/TitleII/Chapter23K/Section2

[9] Applying matching methods to the analysis of sub-community or neighborhood impacts is also not possible due to a lack of sub-city data across all communities and a clear definition of neighborhood. Sub-community and neighborhood impacts can be inferred, in part, through primary data collection.

[10] Zhao (2004) demonstrates that in small samples (n=500 in his study, 100 of which were "treatment" observations), propensity score matching does not perform well compared to other methods.

matching where control communities are selected based on their economic and demographic similarity to casino communities.

Covariate matching is sometimes referred to as nearest neighbor matching and the analogy is useful. We want to select control communities that are most similar to their casino counterparts. This involves developing a score to measure community similarity. Again, without getting too technical, we employ a method known as Mahalanobis matching.[11] A simple example may help illustrate the basic idea of using Mahalanobis distance scores for nearest neighbor matching. Consider two measures, the unemployment rate and the percent of the population with a college degree. To choose Springfield's "nearest neighbors," the values of these two measures in Springfield are compared with the values for every other community.[12] The community with the smallest difference across these two measures is Springfield's best match, the next smallest is the second best match, etc. Every community is ranked in terms of its similarity to Springfield on these two measures.

The economic measures to analyze and the characteristics to use for matching casino and control communities are also important. Given the goal of ascertaining the *economic* impacts of casinos, we focus on a few key economic indicators to assess impact. These include job growth, the unemployment rate, labor force participation, and household income. These are listed and described in Table 2. These indicators, measured prior to the casino opening, are included in our matching characteristics and used in selecting our matched control jurisdictions.[13] Intuitively, if we want to know how a casino changes local conditions related to employment (unemployment, job growth, labor force participation, and household income), selecting control communities that are similar to the casino communities prior to the casino introduction based on these characteristics is an obvious strategy.

In addition, we match communities based on several other economic and demographic characteristics to ensure that our matched communities are as economically and demographically similar to the casino communities as possible. These include: total population; education (*percent with college degree*); race (*percent black*); ethnicity (*percent Hispanic*); poverty (*percent of population below poverty*); and industrial base (*percent employed in manufacturing)*. (See Table 2 for a description)

[11] Mahalanobis matching accounts for the Euclidian distance, sometimes referred to as straight-line distance, between values of the variables for the casino and potential control groups and the correlation between those variables. Mahalanobis matching has been shown by Zhao (2004) to be robust to various settings (sample size, number of matching characteristics, and correlation of matching characteristics) relative to other matching techniques. See Appendix A for more detail.

[12] The absolute difference between Springfield and every other community is calculated for each measure and then summed across both measures.

[13] Zhao (2004) demonstrates that including outcome measures as selection characteristics improves matching.

Table 2: Description of matching variables

Matching Variables	Description	Source
Unemployment Rate	Average unemployment rate (percent of the labor force that is unemployed), 2008-2012.	a
Job Growth	Average annual growth in the number of jobs, 2007-2011.	b,c
Labor Force Participation Rate	Average percent of population over 16 in the labor force, 2008-2012.	a,d
Household Income	Median household income over the period 2008-2012.	d
Percent of Population in Poverty	Percent of population living in poverty over the period 2008-2012.	d
Percent of the Population with College Degree	Percent of the population over age 25 with only a Bachelor's degree over the period 2008-2012.	d
Total Population	Total population over the period 2008-2012.	d
Percent of the Population that is Black	Percent of the population that is Black or African American over the period 2008-2012.	d
Percent of the Population that is Hispanic	Percent of the population that is Hispanic or Latino over the period 2008-2012.	d
Percent of Workforce employed in manufacturing	Average percent of the workforce employed in manufacturing, 2007-2011.	b,c

Sources:
a. Local Area Unemployment Statistics (LAUS), Bureau of Labor Statistics (BLS)
b. Employment and Wages Data (ES-202), BLS and State Employment Security Agencies
c. Longitudinal Employer Household Dynamics Origin Destination Employment Statistics (LODES) U.S. Census Bureau
d. American Community Survey (ACS), U.S. Census Bureau.

The process of matching required gathering the data described in Table 2 prior to any casino construction or opening. We measured these variables over the five year period 2008-2012, with the exception of five year job growth and the percent of the workforce in manufacturing, which were measured over 2007-2011 due to a lack of data from 2012 (as of this date). This time period was chosen for practical and theoretical reasons. From a theoretical perspective, this period includes years from the recession and recovery and captures variation in our matching characteristics over time. From a practical perspective, several of the measures (population, race, ethnicity, poverty, and education) are taken from the American Community Survey (ACS) which is estimated over five year intervals, the most recent of which is 2008-2012.

Control communities were selected from the Northeastern United States, including Massachusetts, Connecticut, Rhode Island, Vermont, New Hampshire, Maine, New York, Pennsylvania, and New Jersey. These states are close to Massachusetts and have a similar economic history and will ensure a sufficient sample of potential matching communities.

The number of control communities to choose for each host community was another important decision. Matching to a single control community can be limited due to the availability of too little information while matching to many control communities results in relying on poorer, more distant matches. We chose five control jurisdictions for each host community in order to balance the tradeoff between too little information and poorer matches.[14] Moreover, a single community may not be the best match across all measures. Choosing multiple communities to create a single "average" control community better ensures similarity to the host community across all matching variables. Finally, it should be noted that while the ordinal ranking of jurisdictions (based on the Mahalanobis score) is useful for comparing the quality of matches for each casino community, they are not comparable across casino communities. The best control jurisdiction for the casino located in Springfield, may not be as close, measured by the Mahalanobis score, as the fifth best control jurisdiction for a casino located in Plainville.

Further Matching Criteria and Results

In this section we describe some final aspects of the process undertaken to select host community matches, namely applying a geographic filter, a size or scale filter and an income filter. Currently there are three known casino locations in Massachusetts. The slots parlor will be located in Plainville (at the Plainridge Racecourse). A casino is planned for Springfield in the western Massachusetts region and Everett has been selected in the eastern Massachusetts region. The location for a possible fourth casino (in southeastern Massachusetts) is still to be determined. Consequently, our focus has been on creating matching results for the three communities of Plainville, Springfield, and Everett.

In addition to the ranking provided by the Mahalanobis score (reported in Table 3 below), three other factors were considered when selecting matched communities.

[14] For example, Abadie et al. (2004) choose four control jurisdictions based on this tradeoff between too little information and using poorer, more distant matches.

Table 3: Host and matched control communities

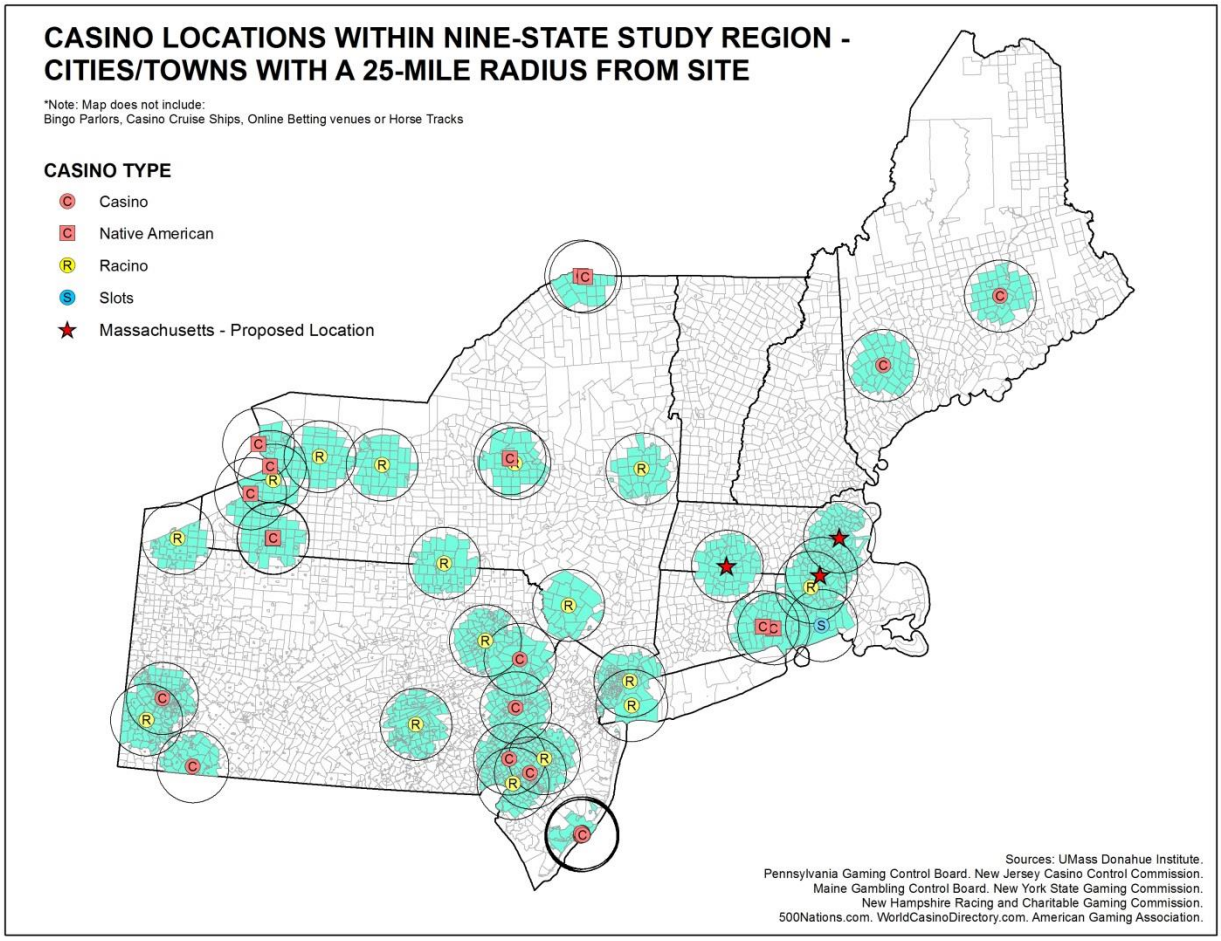
Host and Matched Control Communities													
City/town	Population	Household Income	Percent Black	Percent Hispanic	Percent College Degree	Percent Poverty	Unempl. Rate	Percent Manuf.	Labor Force Partic.	Job Growth	Percent of Host City Population	Percent of Host City Household Income	Miles to Nearest Casino
Springfield, MA	153,278	$35,163	21.6	39.5	10.5	28.7	10.9	5.08	56.97	-0.56	100%	100%	
Bridgeport, CT	144,446	$39,822	35.6	37.4	10.1	23.6	12.06	10.55	59.54	-1.53	94%	113%	40
Worcester, MA	181,473	$45,679	11.3	20	18.4	20.1	8.54	7.25	58.1	-0.51	118%	130%	31
Hartford, CT	124,879	$28,931	37.7	43	8.6	33.9	14.68	1.2	52.67	-1.37	81%	82%	36
New Haven, CT	129,898	$38,482	35	26.5	14.8	26.9	11.56	3.5	55.78	0.58	85%	109%	45
Syracuse, NY	144,703	$31,459	29.3	7.6	14.5	33.6	9.12	3.61	54.95	-3.01	94%	89%	28
Average match community	145,080	36,875	29.8	26.9	13.3	27.62	11.19	5.22	56.21	-1.17	95%	105%	36
Everett, MA	41,621	$49,702	14.1	19.8	11.6	12.8	7.44	7.34	60.01	-1.55	100%	100%	
West Haven, CT	55,386	$51,911	19.7	16.2	12.7	11.7	9.18	7.63	68.53	-1.73	133%	104%	47
Poughkeepsie, NY	44,357	$68,886	9.1	9	19.2	10	7.36	18.18	58.75	-1.52	107%	139%	41
Salina, NY	33,682	$51,952	4.3	3.5	14.7	8.4	7.34	16.78	64.21	-0.4	81%	105%	28
Leominster, MA	40,879	$59,604	5.7	13.4	17.6	9.9	9.16	15.97	61.44	-1.62	98%	120%	46
Middletown, CT	47,530	$60,542	12.8	8.7	19.7	10.9	7.68	14.56	68.46	-3.18	114%	122%	30
Average match community	44,367	$58,579	10.3	10.2	16.8	10.18	8.14	14.62	64.28	-1.69	107%	118%	38.4
Plainville, MA	8,278	$83,750	0.9	1.7	26.6	4.7	8.44	11.93	76.89	-0.53	100%	100%	
Haddam, CT	8,308	$89,184	0	2.3	27.4	3.8	5.76	3.7	78.94	0.31	100%	106%	23
Atkinson, NH	6,756	$82,889	0	1.8	26.5	4	6.24	8.89	70.96	-1.15	82%	99%	67
Pepperell, MA	11,537	$85,150	0.2	1.6	26	4.2	6.22	6.34	70.69	-0.85	139%	102%	54
Portland, CT	9,500	$92,344	1.2	3.8	25.1	5.1	6.98	13.06	70.01	-2.05	115%	110%	27
Sturbridge, MA	9,230	$83,375	0.2	4	24.3	9	6.78	10.42	70.57	0.15	112%	100%	36
Average match community	9,066	$86,588	0.3	2.7	25.9	5.22	6.4	8.48	72.23	-0.72	110%	103%	41.4
Average Massachusetts community	23,897	$78,971	2.74	4.77	23.17	7.39	7.02	10.04	67.42	-0.61			

First, to ensure that matched communities are not also influenced by a casino, communities completely within 25 miles of an existing casino were considered ineligible as matches (see Figure 1). This distance was based on economic and practical considerations. Economically, in the Northeast it is unlikely that a casino will have significant employment and economic impacts beyond a 25-mile radius. Practically, to expand beyond 25 miles greatly reduces the number of potential matching communities. A 25-mile radius ensures that our control communities are not influenced by a casino and allows for sufficient high-quality matches. The distance of each control community, measured from the city center, to the nearest casino is reported in Table 3. The average distance of our control communities to the nearest casino is 38.6 miles. While the city center of Haddam, Connecticut, a control community for Plainville, Massachusetts, is 23 miles from the nearest casino, not all of Haddam lies within the 25 mile radius, hence its eligibility. While we are confident that the selection of Haddam as a control community will not unduly influence the results of our analysis, we plan to verify this by comparing results when including and excluding Haddam as a potential control community.

Second, matched communities should be similar in size to their host community counterparts. Specifically, a matched community's population should be between 75 percent and 150 percent of the casino host community to be eligible. As shown in Table 3, however, most matched communities are well within these bounds and the average population size of our five matches is very close to their host community counterparts.

Third, matched communities were filtered to have similar household income characteristics. In this case, we sought communities with median household income between 75 percent and 150 percent of the host community to be eligible as a match. After applying this criterion, most matched communities are closer than these bounds and the median household income levels of our five matches are very close to their host community counterparts.[15]

Figure 1. Communities within 25 miles of existing and proposed casinos



After applying the above criteria, the top five matches for each of the potential casino host communities are shown in Figure 2 and the values of the matching variables are provided in Table 3. Table 3 also provides the averages of the five matched control communities. These can be thought of as a combined or conglomerate control for comparison with the casino

[15] We also eliminated beach resort communities since these are likely to be different economically from our casino communities (e.g., Riverhead, NY on Long Island was eliminated as a match for Everett). Formally accounting for tourism, for example by including hotel occupancy rates as a selection variable, is not possible due to a lack of data.

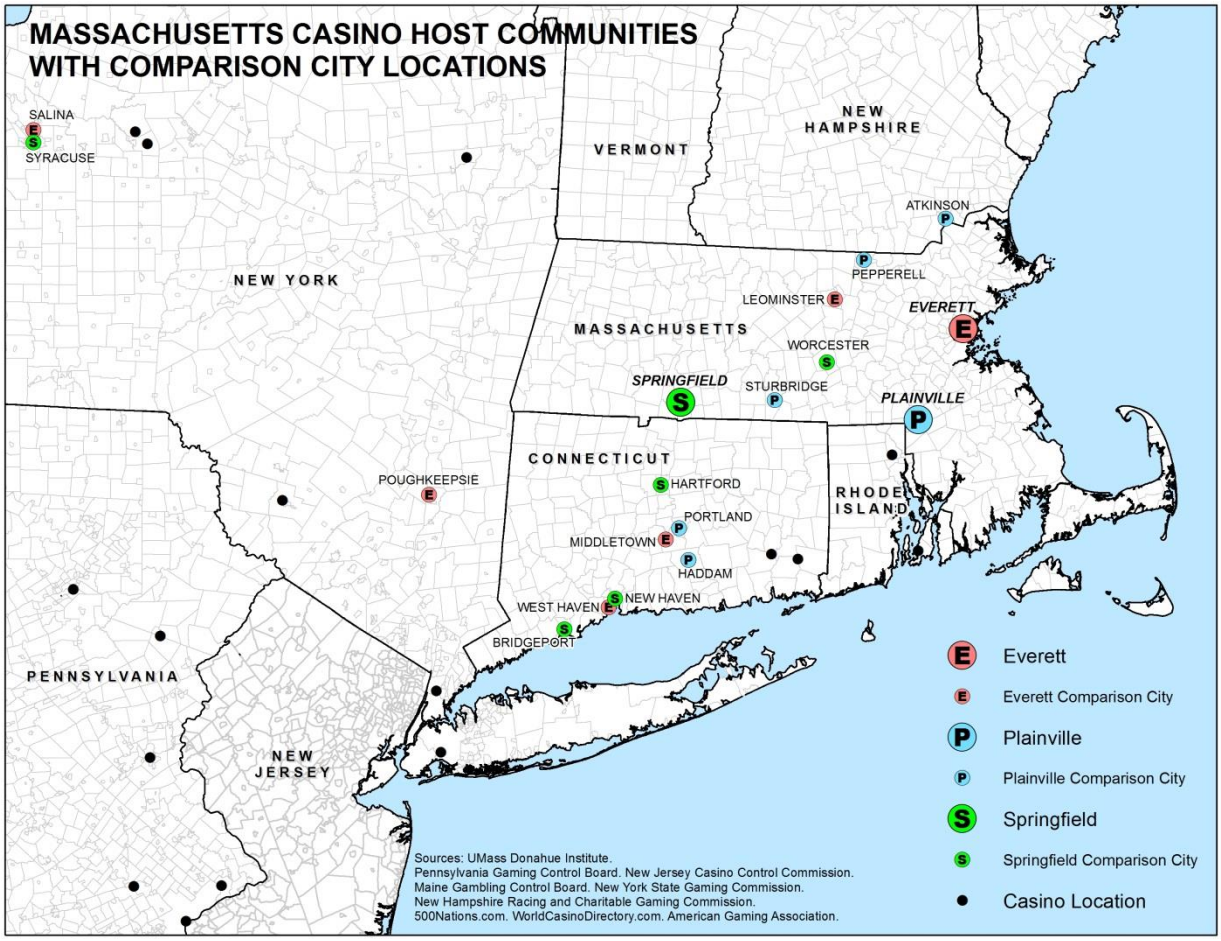
jurisdiction. The advantage of comparing each host community with an "average match" is that it better ensures similarity across all selection characteristics. Table 3 also provides averages of the matching variables for Massachusetts (across all communities in the state).

Table 3 clearly shows that the casino host communities are quite different from Massachusetts as a whole. For example, with the exception of Plainville, the host communities have lower median household income, higher rates of poverty, and a lower proportion of residents with a college degree than Massachusetts. In contrast, our matched control communities are much more similar economically and demographically to our casino host communities.

As discussed above, communities may adopt casinos in part because they are economically and demographically different from other communities in the same region or state. Table 3 demonstrates these differences and highlights the advantage of using matching methods to select economically and demographically similar communities to compare with the host communities. For example, Springfield has lower household income and percent of the population with a college degree and a greater proportion of the population living in poverty than Massachusetts as a whole. Our matched control communities for Springfield, by comparison, have similar values for these characteristics.[16] While there are differences between host and control communities in some individual characteristics (for example, Syracuse has a lower percent of the population that is Hispanic relative to Springfield), overall our matched control communities are more similar to our casino host communities than Massachusetts as a whole. This can clearly be seen when comparing the host communities with the "average match." In addition, for each host community the matched control communities are dispersed across two to three states (with at least one in-state Massachusetts match for each host community). This geographic dispersion is intended to minimize the chances that our control communities will be influenced by local economic shocks or the casino openings in Massachusetts. As a whole, comparison of the casino host communities with our matched control communities, whether individually or with the "average match," can better account for economic and demographic variation between communities and increase confidence in our estimated economic impacts.

[16] After applying the filters, especially the population thresholds, there are relatively few qualifying matches for Springfield. Even though its Mahalanobis score is quite a bit higher than the other matches for Springfield, Syracuse's economy is largely similar to and consistent with that of Springfield so we still felt comfortable using it as a match.

Figure 2. Massachusetts host communities and matched control communities



Future Work

Once casinos open in Massachusetts, data on unemployment rates, job growth, labor force participation, and household income can be gathered for the host communities and the identified matching comparisons. How these key economic variables perform over time in the host communities compared to the matched comparisons will then present an insightful assessment of the economic impacts of introducing casinos. Other methods, including comparing host communities with pre-casino trends, with Massachusetts as a whole, and with results from an economic impact simulation model using REMI, will also be used and explained in more detail in future reports. In addition to the analyses described above, other components of the overall study, such as primary data collection about employees, patrons, and gaming venue expenditures, and information gathered from communities, will complement the economic analysis.

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Appendix A

Difference-in-Differences

The calculation for difference-in-differences is as follows:

$$(Y_{co} - Y_{cp}) - (Y_{mo} - Y_{mp}) \quad (1)$$

where Y is our outcome of interest, e.g., unemployment, and subscripts reference the jurisdiction (c=casino; m=matched control) and time period (o=casino open; p=prior to casino open)

Matching Metrics

The Euclidian distance is measured as follows:

$$d(c,n) = (\sum_{j=1}^{k}(X_{c,j} - X_{n,j})^{2})^{1/2} \quad (2)$$

where $X_{c,j}$ is the jth variable for the casino jurisdiction and $X_{n,j}$ is the jth variable for the non-casino jurisdiction. Summing across all k variables provides a distance measure between the casino jurisdiction and each non-casino jurisdiction. Non-casino communities with the smallest distance measure are nearer neighbors and better matches.

This is frequently presented as

$$d(c,n) = ((\boldsymbol{X}_c - \boldsymbol{X}_n)'(\boldsymbol{X}_c - \boldsymbol{X}_n))^{1/2} \quad (3)$$

where X_c and X_n are a vector or matrix of the matching variables for the casino and control variables, respectively. The k variables are frequently standardized to have a mean of zero and variance of one to account for differences in measurement.

The Mahalanobis distance is measured as follows:

$$d(c,n)_M = ((\boldsymbol{X}_c - \boldsymbol{X}_n)'S^{-1}(\boldsymbol{X}_c - \boldsymbol{X}_n))^{1/2} \quad (4)$$

where S^{-1} is the variance covariance matrix between the matching variables. This generalizes to the Euclidian distance when the independent variables have unit variance and zero covariance.