

Data Science For Social Good Europe

Summer Fellowship

CASCAIS



Data-Driven Planning for Sustainable Tourism in Tuscany

Io Flament, Cristina Lozano, Momin M. Malik
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Executive Summary

The region of Tuscany and the city of Florence are top tourist destinations globally. The metropolitan city of Florence, with its 380.000 residents, is the choice of over 5 million tourists per year with the number of tourists growing every year; the growth from 2012 to 2016 was 10%. The city center alone receives around 3,5 Million tourists every year.

While tourism is a fundamental pillar of the economy of the city, there is a lively debate on the balance between the economic benefits of tourism, the impacts on the city fabric and resources, the degradation of communities and the loss of identity of places.

At the Data Science for Social Good Europe Summer Fellowship, based in Cascais, Portugal and with the support of the University of Chicago's Center for Data Science and Public Policy, we analyzed novel sources of data to understand patterns of tourist behavior.

The project partner, Toscana Promozione Turistica, and data partner, Vodafone Italy, provided anonymized data that was used to identify patterns of tourism in both time and space. The project was designed to support local authorities to understand and measure tourism through the use of data, beyond traditional surveys and official aggregated statistics as well as to explore and design solutions for sustainable tourism in the city.

A vision for smart tourism in Florence

Tourism around the world is changing. Larger populations now have the budget for travel and the awareness of historic destinations. High-speed trains and low-cost airlines give greater mobility options. Online resources such as travel information sites, social media, and mapping applications help people aspire to destinations and plan itineraries. Cities working with analog management of their cultural resources may be ill-equipped to react to new patterns of mass tourism. Sites around the world have faced numbers of tourists higher than can be accommodated, with some high-profile examples of cultural sites being Machu Picchu in Peru and the Great Wall of China. In Barcelona, Dubrovnik, and Venice, mounting resentment about negative impacts of tourism felt by residents have led to anti-tourism protests, leaving local, regional, and national governments to ask how they can accommodate tourists and sustain the sector while maintaining the quality of life for locals and residents.

The city of Florence has already made remarkable innovations in its tourism management. The Firenzecard, a museum card that creates a common entry scheme for the top 72 attractions in Florence, is a major achievement in making the city accessible and spreading visits among museums. The digitized information point at Santa Maria Novella is an exemplar of convenience, efficiency, service, and data collection.

We outline a vision of a future system of smart tourism management in Florence, where the digital traces created by new tourists can feed back into the city's knowledge of tourist patterns to inform decision-making and management. It is difficult to have effective management policies without fully understanding the current situation, so with our work, we attempt to shed light on what current

data sources can tell us about what is happening in the city. Additionally, we discuss future data collection strategies that will give the data for a future system of monitoring and managing tourism.

Key findings

1. Using telecommunications data, we estimate that during summer months, there is one tourist for every two residents in Florence (150.000 daily tourists for 375.000 residents).
2. Also from telecommunications data, we estimate that the majority of visitors to Florence stay for one day or less (including those who do not stay overnight). This can update the previous estimates of the average length of stay, based on accommodations data, of 2,6 nights per person.
3. Also from telecommunications data, we estimate that about a fourth of all one day excursionists to Florence enter from the Santa Maria Novella train station.
4. From national and state museum visit numbers (which does not include Opera del Duomo sites), the Uffizi Gallery, the Accademia Gallery, and the Palazzo Pitti museums together account for 72,5% of all museum visits over the summer months.
5. There is evidence that the Firenzecard has been successful in its goal to encourage visits to smaller museums, as a larger proportion of smaller museum entries are on the Firenzecard.
6. Many people buy the Firenzecard only to skip lines, as evidenced by people who see only a few or even only one museum over the entire 72 hour period of the card. However, these people account for a minority of visits to major museums, and also a minority of Firenzecard users (who, on average, visit 6 museums on the card).
7. Many people use the Firenzecard in pairs or larger groups. The most common type of Firenzecard usage (half of all Firenzecard usage) is two adults, travelling together without children. Second-most common (one fifth) is solo adult travelers. Those traveling with children, and larger groups, make up the remainder of Firenzecard usage.

These represent the kind of insights that are now available for Florence and Tuscany. Building on data management practices can lead to even more extensive and precise insights about tourism patterns in the region, which in turn can feed back into planning and tourism management that can spread the benefits of tourism and lessen the burdens, and ultimately work towards a future of sustainable tourism.

Introduction

Our goal in approaching this project was to find the intersection between the questions that are important for tourism planners to know the answers to, and the questions that we are able to answer with the novel sources of data provided to us by our partners.

Key questions

The key questions we identified, and the ways in which they are important, are:

Where are the tourists at a given time?

Knowing which areas tourists occupy at different times of the day makes it possible to target these areas to provide more resources, or restructure the areas to accommodate large crowds. Knowing which nearby areas are underused at the same times of the day will provide additional valuable information that can be leveraged to encourage movement from one area to another. Understanding the temporal dynamics of crowding within the city is also essential to public safety planning and assessing the impact of tourism on the resident population.

How many tourists are there?

The city of Florence has an inherent *carrying capacity* in each of its neighborhoods and institutions. The most basic notion of this is the physical capacity of the number of people who can safely fit in a space: for example, each museum has a defined maximum occupancy that cannot be exceeded, and accommodations have a fixed number of beds and rooms. In order to know the scale of the overcrowding, it is necessary to first know the total number of tourists in each region of the city at each time of the day to compare against known physical limitations.

Where do tourists come from and where do they go after?

Knowing the predominant nationalities of tourists in the city allows tourism services, airports and railway to print guides and materials in the appropriate languages. Knowing where travellers come from directly before they arrive in Florence could help to identify which transit services are being most utilized and the impact of each of these modes of transit on the cycles of crowding in the city center. If certain modes of transit are more detrimental or useful than others, policies can be targeted more specifically.

How long do tourists stay?

Each type of tourism produces a different impact on the city. Tourists that stay overnight for one night provide an economic boost to the accommodations industry, but will likely only visit major attractions. Tourists that stay multiple days will also have more time to explore the less well known sites in the city, potentially outside of the city center. Tourists that visit just for the day, which we label ‘excursionists’, also are likely to see only major attractions but may even only go to public places. These categories of tourism likely produce different strains on the infrastructure of the city and also require differing tourism information and recommendations.

What do tourists visit during the day and when?

Florence has a variety of types of attractions, such as churches, art museums, science and history museums, retailers, restaurants, and more. Knowing the primary attractors for tourists to the city helps structure future tourism advertising and allows information centers to provide better tips and suggestions for possible itineraries based on categories of tourism. Having suggested itineraries is one possible way to give tourists information that can help encourage them to discover less popular attractions. Additionally, knowing peak hours for every museum is helpful for planning crowd management in the areas around the attraction. It is also information that can be provided to visitors to encourage them to schedule their days differently, for example by telling them the most crowded times of day to avoid (and if enough visitors take these suggestions, in aggregate it would distribute crowds over the course of the day).

Having compiled these questions, we considered which could be best answered with the data collected by our partners and data providers: these are **the numbers of tourists, their length of stay, and visiting patterns of their trips**.

Focus of the work

While many of these questions seem basic, it is surprisingly difficult to get full answers through traditional methods such as survey and accommodation data. Studies based on surveys (*Il Turismo a Firenze: Il Punto di Vista dei Residenti*, Comune di Firenze, 2016) provide irreplaceable insight into motivations and feelings of both tourists and locals, but have the difficulty of having relatively small sample sizes with nonrepresentative sampling frames, and do not have high temporal resolution for capturing hourly or even daily patterns of behavior. Estimates of numbers of tourists have traditionally come from the number of monthly overnight stays in all the hotels in Florence, divided by the number of people who make overnight stays. However, these types of estimate from accommodation data alone only capture people who stay for at least one night: they miss the more transient categories of tourists, such as excursionists, which our analysis suggests make up a significant portion of people present in Florence (details below).

Our work focuses on using data that has already been collected in the city of Florence to do a case study of the state of tourism during the summer of 2016. Using previously separate sources of data and cross-referencing them, we can develop a more detailed breakdown over a wide scope of tourism movements that helps to enrich the currently collected statistics for the city.

Data Analysis

Exploratory data analysis of all datasets

In line with final project objectives and key questions of interest for partner organisations, choices were made to focus on the following sources: Firenzecard data, State Museum data, Telecommunications data, and tourist info center data.

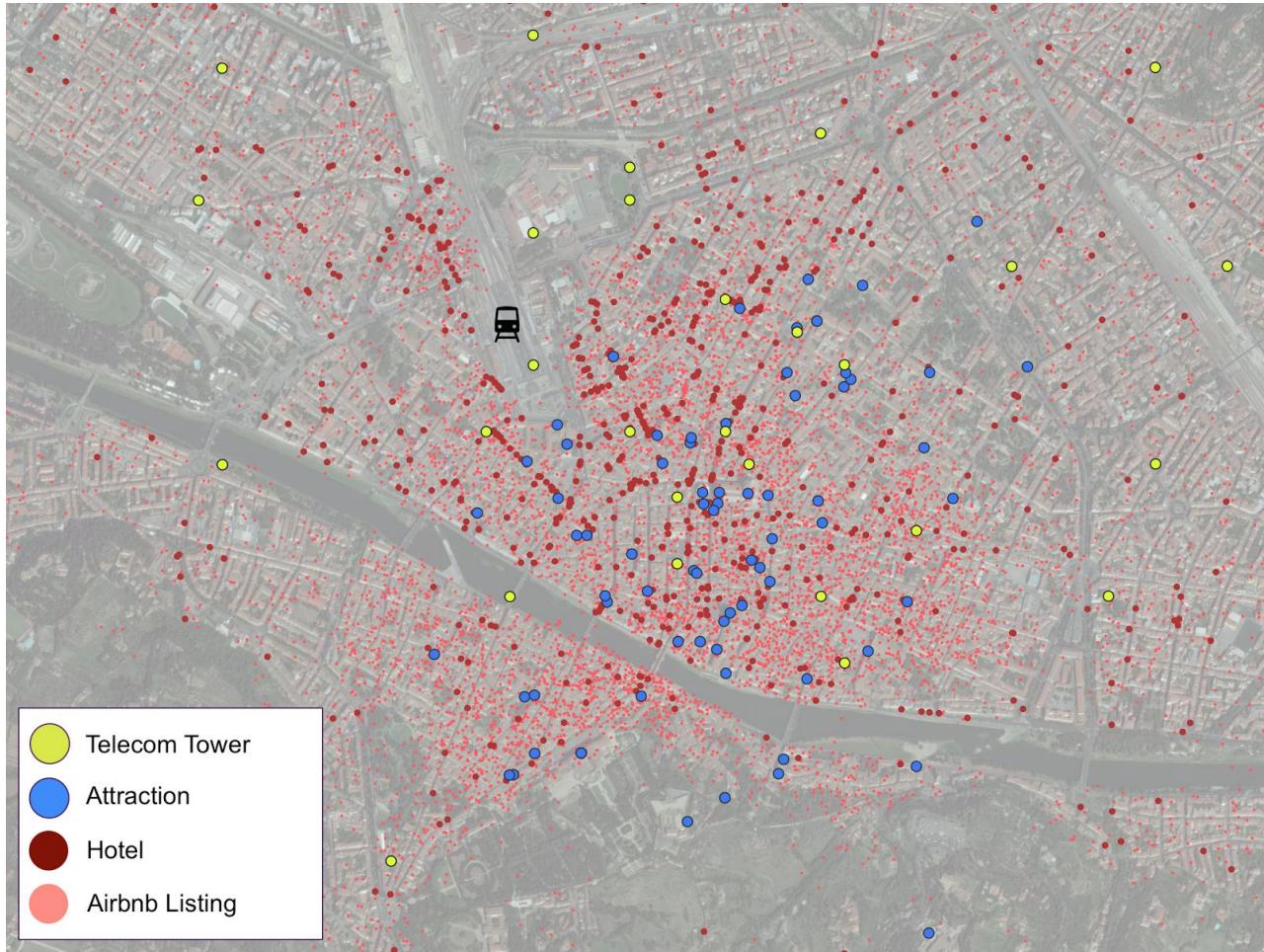


Figure 1. Map of all touristic attractions, accommodations, and cell phone towers in Firenze. Most of the main attractions in Florence are concentrated in a small area of only a few square kilometers in the region just north of the Arno. We see that a single telecom tower services any attractions in the city center. We additionally see that traditional accommodations are limited to specific streets but that Airbnb covers the entire city.

Macro level analysis using Telecom Data

The telecommunications data shared by Vodafone Italy provides us with larger or ‘macro’ scale patterns and flows of people visiting Florence. Here, ‘macro’ level patterns are at the level of city neighborhoods, in contrast to ‘micro’ level patterns that are at the level of city blocks or even individual buildings.

The data provided is Call Detail Records (CDR) from 1st June 2016 through 30th September 2016. A Call Detail Record is created whenever a phone call is placed or received from a mobile phone on a given provider’s network. These are also called circuit switching data, as within telecommunications engineering, placing or receiving a call involves a switch of an electronic circuit. These records contain:

- the anonymized user identifier for the customer,
- the nationality or home region in Italy of the user’s SIM card,
- the date and time of the event, and
- the coordinates of the tower that handled the call.

CDR can potentially contain text message (SMS) data as well, although SMS records were not present in our data.

In contrast to circuit switching data, there is also *packet switching* data, which are the records of the constant contact between mobile devices and cell phone towers (this constant contact is, for example, how a mobile device displays the number of “bars” to indicate the strength of available cell phone tower coverage). Packet switching data was not available for the months we considered, although in the future this type of telecommunications data could give more detail than circuit switching. Circuit switching samples a mobile device user’s location only when they choose to place a call or happen to receive a call, but packet switching data samples their location regularly.

We were given a subset of the CDR that contained records just for foreign or Italian tourists from their visit to the province of Florence during our target time period, plus the records 3 days before and after their visit. Filtering out Florence residents was done by CS Research by removing people who consistently appeared in Florence at nights over a set period of time. This filtering was done because, for residents, call records are especially sensitive: even though the call records are anonymous, seeing where people consistently go at night and during the day could, in theory, partially re-identify and de-anonymize individuals.

See Appendix A for a technical discussion of limitations.

Exploratory data analysis

With the help of CS Research, we created plots of call activity in Florence over the summer of 2016 as well as a breakdown of types of customers. These graphs chart the number of *presences* in Florence over the summer of three categories of people: Italian visitors, foreigners, and residents. The values for presences are estimated from the CDR data based on multiple factors, such as call behavior trends, local demographics, and cell phone carrier market share. Presence is defined as the number of unique people seen in Florence over 1 day independent of the duration of stay, rather than the number of people present at one point in time (which will be strictly less than the presences). *Italian visitors* are people with SIM cards from Italy whose home is outside of the city of Florence. *Residents* are people who live in the city of Florence. This distinction can be made by looking at the home region associated with the SIM card and from the calling patterns of the customer. *Foreigners* are people with foreign SIM cards visiting the city of Florence, with the nationality coming from the nationality of the SIM card. Note that foreigners who buy Italian SIM cards on arrival for use will appear in the data to be Italian.

The following graphs help us to answer our initial questions of how many tourists are in the city of Florence and where do they come from.

Total Estimated Presences in Florence per Day

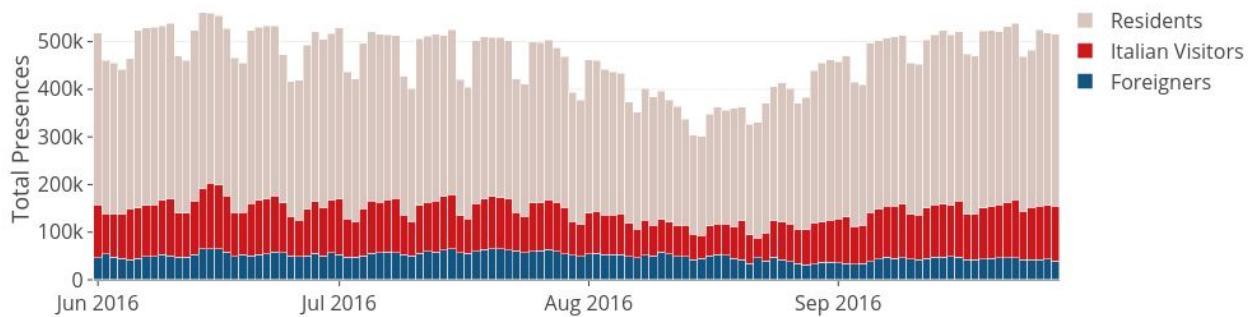


Figure 2. The total estimated presences per day for all types of people in the city of Florence during the summer. We can see that on an average day, one third of the people in the city are tourists. That ratio increases in the month of August as foreign tourism remains somewhat constant, whereas the resident population makes a dip. We can also see cyclic activity that is likely due in part to reduced calling on weekends.

Estimated Presence of Foreign Visitors in Florence per Day

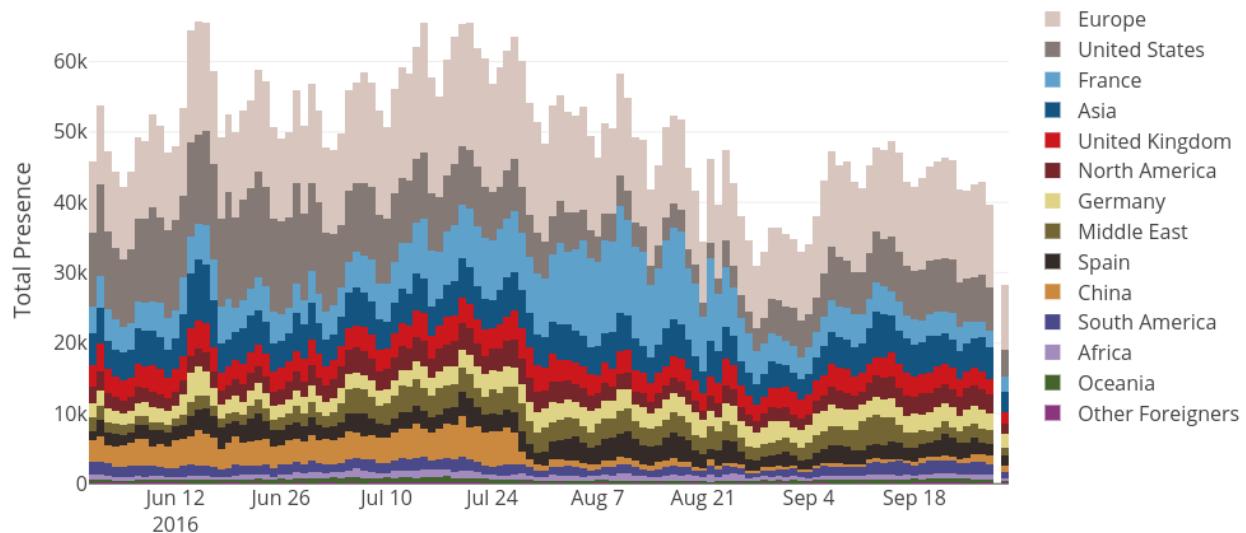


Figure 3. The breakdown of the estimates for foreign presence. The breaks are done by region of the world, with the most common tourist countries (The United States, France, Germany, Spain, and China) plotted separately instead of aggregated into their region. This shows that peak visiting months are not the same for

every country.

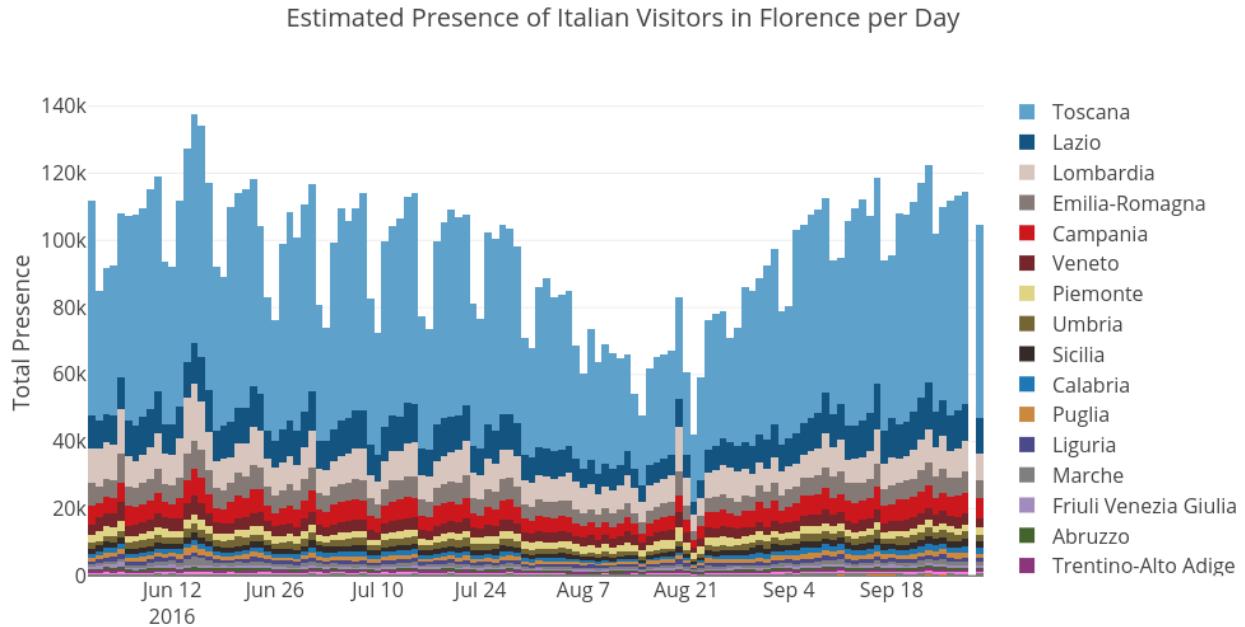


Figure 4. The breakdown of the estimates for presence of Italian visitors. We see that the majority of Italian visitors to Florence come from elsewhere in Tuscany.

Length of stay

Having detailed call records for customers visiting Florence allowed us to do more complex analysis on how often tourists visit the city and how long they stay when they do. We did this by grouping sets of call records into trips, which we define as *groups of consecutive calls with gaps of no more than two days between calls*. Using that metric, daytrips out of the city or short weekends trip are counted as part of the same trip to Florence.

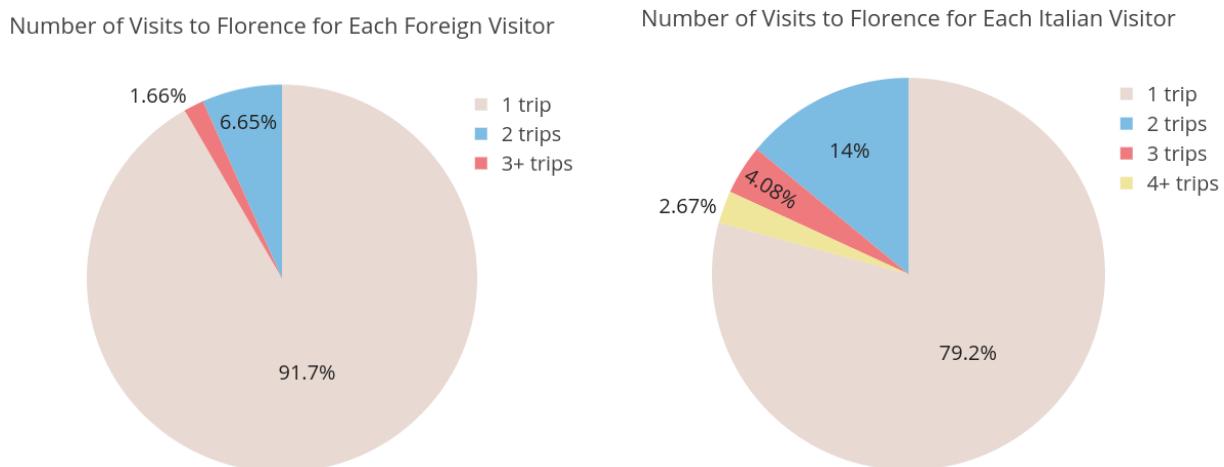


Figure 5. The breakdown of the estimates for number of visits foreign and Italian visitors make to the city of Florence during the summer months of 1st June 2016 through 30th September 2016.

We see from our analysis that the vast majority of foreigners only make one visit to Florence in the four month summer period in 2016. Italian visitors also largely only make one trip over the summer,

but we do see that there is a higher percentage of people coming for repeat trips. When investigating the subset of foreign users who make two trips to Florence, we see the common pattern that these people are active in Florence for a day, leave the city to go around other regions of Italy, and then return only briefly and are often picked up at the telecom towers near the airport or train station. That being said, the two trips number is somewhat deceptive since many of those pairs of trips represent a roundtrip trip out of Florence.

For our analysis of trip length, we are mainly concerned with people who only made one trip to Florence since we don't want to include any second trips that are just brief stopovers in our calculation. Since the majority of our dataset only make one trip, we used this subset to calculate trip length. The trip length calculation is based off of the number of calls we see from a customer over their trip in Florence. These percentages are estimates and could possibly be skewed towards being shorter since a person who makes a couple of calls their first day and then never again on their trip will count as a person who only stayed one day.



Figure 6. The breakdown of the estimates for how many days foreign and Italian visitors stay in the city of Florence during the summer months of 1st June 2016 through 30th September 2016.

From our analysis, we see the majority of foreign and Italian visitors only stay one day in the city. This is a critical finding since it contradicts the average length of stay as seen from accommodation data, but is in keeping with the intuition of the employees at the tourism information center who say that most of the people who come through are coming for the day.

Places and relationships between places

Excursionists

As seen above from 1st June 2016 to 1st October 2016, around 80% of Italian tourists and about 60% of foreign tourists who make one trip to Florence only make calls on one day in the city on the Vodafone network. These people are most likely what we define as *excursionists*, also known as one

day visitors or daytrippers. We are interested in investigating these tourists to see what they do in their limited time in the city. They are the tourists that have been least observed and counted by the tourism estimates from accommodation data, since many of these excursionists do not stay in the city overnight.

Fountain visualisation

We took a subset of these excursionists and mapped how they move around the city in an attempt to better understand this type of tourist. We selected 7,000 foreigners and 7,000 Italian visitors that have a dense pattern of activity, which we define as a person who made more than fifteen calls in their day in Florence, so that we can map the paths that they take. From this visualization, for every region of the city, we can see where people came from to get there and where they are likely to go next.

Each polygon in the visualization is a *Voronoi cell* drawn around approximated locations of telecom towers in Florence. A *Voronoi diagram* is a set of polygons (each polygon is a ‘cell’) that are built from a set of points called generators. For each generator there is a corresponding polygon drawn around it that contains all the points closer to that generator than to any other. This means then that a polygon estimates the region of coverage for each tower. Each region is given a unique tower identifier and also is labeled with some of the major attractions that fall within its boundaries. The darkness of a polygon indicates the popularity of an area with excursionists, where darker means more people are present normalized by the area of the shape.

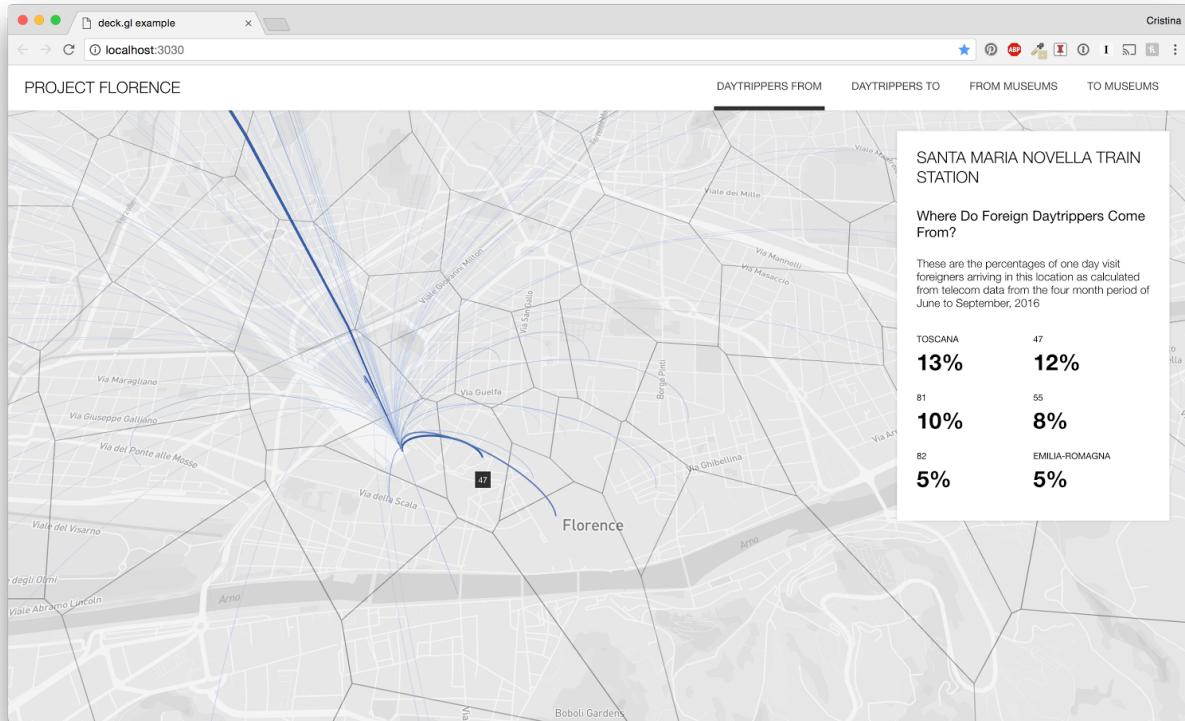


Figure 7. The interactive fountain network built to visualize excursionists to the city of Florence during the summer months of 1st June 2016 through 30th September 2016.

From this analysis we see how commonly a person goes from one region to the next. In developing this network, we learn the breakdown of where excursionists come from before arriving in Florence as well as where they go after they leave.

Most Frequent Origin and Destination

Italian Excursionists			Foreign Excursionists		
Region	% Origin	% Dest	Region	% Origin	% Dest
Toscana	48%	50%	Toscana	45%	47%
Emilia-Romagna	21%	19%	Abroad	29%	29%
Lazio	8%	8%	Lazio	8%	8%
Abroad	7%	7%	Emilia-Romagna	7%	6%
Lombardia	6%	5%	Veneto	4%	4%
Umbria	4%	3%	Liguria	2%	2%

Table 1. The breakdown of where we see foreign and Italian excursionists before they enter and after they leave the city of Florence during the summer months of 1st June 2016 through 30th September 2016. When there are no CDR records from before or after the visit to Florence, that is marked as abroad.

As expected, most people begin their visit in Tuscany directly before entering Florence, but there is also a high percentage from Emilia-Romagna and Lazio, and we can see that especially strongly around the tower regions surrounding Santa Maria Novella train station. We see that the most common origin and destination regions are not the same for Italian tourists and foreign tourists. Notably, we see that a large percentage of foreign excursionists come from and leave to locations outside of Italy, unlike Italian excursionists. We see that only 7% of Italian excursionists come from abroad and go back abroad again. These could be Italian citizens, but they are also potential foreign tourists who purchased SIM cards in the city.

This same type of analysis also shows us what regions of the city of Florence are most common for excursionists to be seen first and last.

Most Frequent Entry and Exit Locations in Florence

Locations	% of Entries	% of Exits
Santa Maria Novella Train Region	26%	27%
Uffizi, Ponte Vecchio, Palazzo Vecchio Region	7%	8%
Airport Region	5%	5%
Via di Mezzo, Museo Ebraico, Casa Buonarotti Region	4%	5%

Table 2. The breakdown of the most common regions where foreign and Italian excursionists start and end their trip in the city of Florence during the summer months of 1st June 2016 through 30th September 2016. The most frequent entry and exit regions happen to be the same, but will not necessarily always be.

Some of these observations are as expected, like the most common entry point being via the train. The next most common first sighting point is near Region 55, which contains the most major attractions in Florence, such as the Uffizi, Ponte Vecchio, Palazzo Vecchio, and the Mercato del Porcellino. The excursionists are most likely to start in the most crowded city center area of Florence and are unlikely to go outside of that region. Given that they only have one day in the city, it follows our intuition that without any intervention or tourist office guidance, these visitors would head only to the top sites.

Micro level analysis of tourist movements using Firenzecard data and State Museum data

The Firenzecard is an electronic card for facilitating visits to the cultural heritage sites of the city of Florence. Card holders are automatically provided with general admission, tickets for exhibitions, and priority access for every museum of the Firenzecard circuit with no reservations required. The card allows its users to visit 72 key tourist attractions and museums in Florence, and is active for a duration of 72 hours from the first use. EU Minors under 18 years of age are granted free admission on the cards of an accompanying adult family member.

The Firenzecard dataset used for this study consisted of attraction entry information of Firenzecard users during the time period of 1st June 2016 until 30th September 2016. This accounts for a totality of 51.031 cards. Since minors can enter along with adults on a Firenzecard, the number of cards and cardholders is not the same as the total number of people who enter on the card. There are a total of 58.411 people who entered museums with Firenzecards over the summer.

A data entry log is created each time a person uses their Firenzecard to enter a museum or touristic attraction part of the circuit of 72 tourist attractions of the card. Each entry contains: an anonymized user identification number, the date and time of entry, a field detailing whether or not the entry was the first entry to be made on the card, the name of the tourist attraction visited, and the number of minors also entering on a card. The entry time for all minors entering on a single card is identical (i.e., a card scan is not separately recorded for each entering minor).

See Appendix A for a discussion of limitations of the Firenzecard data.

Scaling from Firenzecard to total museum entries

The Firenzecard gives rich information about the visiting patterns of cardholders, but the majority of museum entries are not on the Firenzecard. By comparing the relative entry rates for museums in general and Firenzecard users, we can try to scale up the patterns we find in the Firenzecard to the total population.

The state museum dataset provided is a monthly aggregate of the number of visitor entries at national state museums, allowing to make broader estimates of the total count of tourists visiting

attractions during the period of 1st June until 30th September 2016. There is a large but not total overlap between Firenzecard sites and state museum sites. Most visitors of museums and tourist attractions purchase the normal museum tickets without the card, however approximately 10% of all museum visitors recorded in the summer 2016 entered on the Firenzecard (Figure 8).

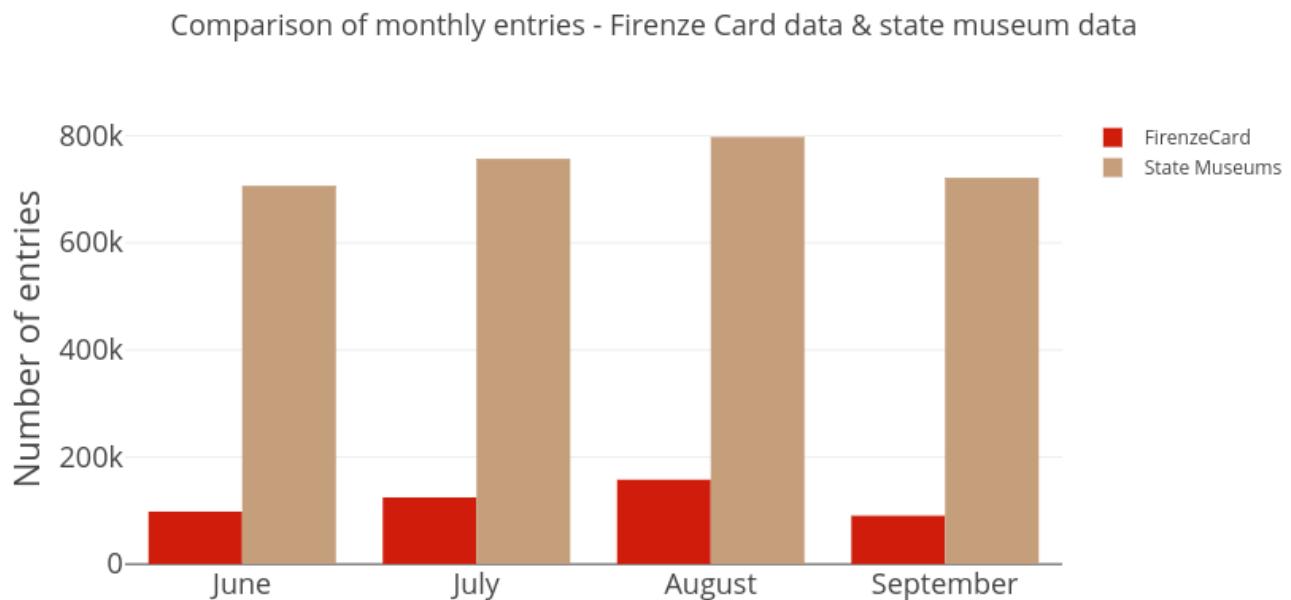


Figure 8. Comparison of monthly entries for Firenzecard data and state museum data. Firenzecard users only represent a small proportion of the total number of museum visitors over summer 2016.

On average across all months and museums, 10% of museum visits are from Firenzecard visitors, and as a rule of thumb we can multiply any Firenzecard numbers by 10 to estimate total museum entry numbers. However, more precisely, Figure 9 shows that the more total entries a museum has, the fewer of those entries are on the Firenzecard. So, Firenzecard visitors make up a smaller percentage of the total visitors to large museums (Uffizi, Accademia, Palazzo Pitti). We discuss above that we do find some evidence that many people buy the Firenzecard just to skip lines at major museums, but here we see that the overall number of people doing this is small compared to the total number of people attending these museums.

Figure 9 shows that indeed, relatively more people enter small museums on the Firenzecard. Without running experiments, we do not know with certainty if the Firenzecard itself causes people to attend less visited museums that they would have otherwise not attended, but this is give evidence that the Firenzecard has been successful in its goal of encouraging attendance at smaller museums.

Firenzecard usage is also not constant over time: all museums have more Firenzecard users for the month of August than on other months, although their absolute number of visitors remains relatively constant, suggesting that August visitors are slightly different from visitors at other times of the year. This may be due to fewer Italian visitors in August, or simply that visitors at the height of tourist season are more inclined to take advantages of the Firenzecard.

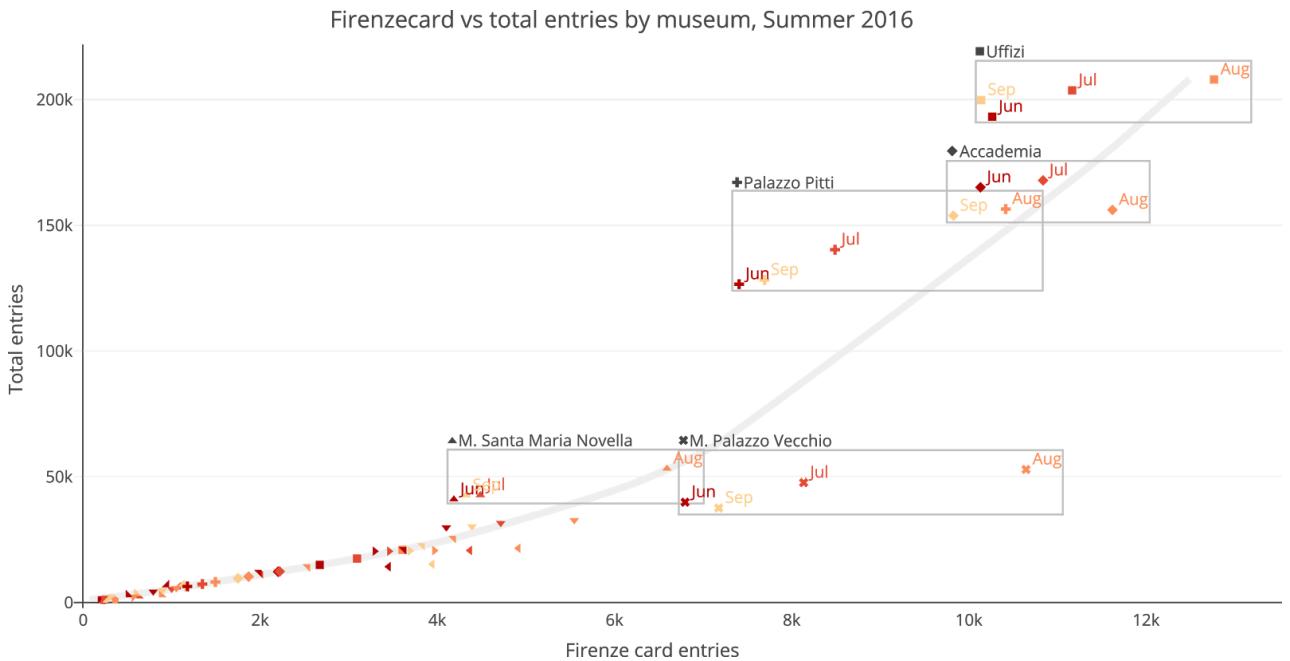


Figure 9. The relationship between people entering on the Firenzecard and total museum entries, for the four months of summer 2016. The relationship changes from month to month; we can see that the same museum (same shape) over different months tend to line in a horizontal line, meaning that the proportion of Firenzecard entries changes while the overall total remains stable. August in particular sees far higher proportions of Firenzecard entries. The thick gray line shows the estimated overall relationship between Firenzecard entries and total museum entries.

Exploratory Data Analysis

Exploratory analysis of the Firenzecard dataset reveals the patterns of usage behaviour of all 51.031 Firenzecard holders during the time period of 1st June 2016 until 30th September 2016. The analysis is structured around the main key questions concerning this subpopulation of museum visitors.

What are the most popular state museums visited without the Firenzecard?

The three top visit destinations of the national or state museums are the Uffizi (average of 201.164 entries), the Accademia (average of 160.774 entries) and the Palazzo Pitti (average 137.912 entries). These three museums account for around 67% of all the entries to state or national museums for the summer. This indicates that only a few museums are the primary attractors in Florence.

Average Total National and State Museum Entries for Summer 2016

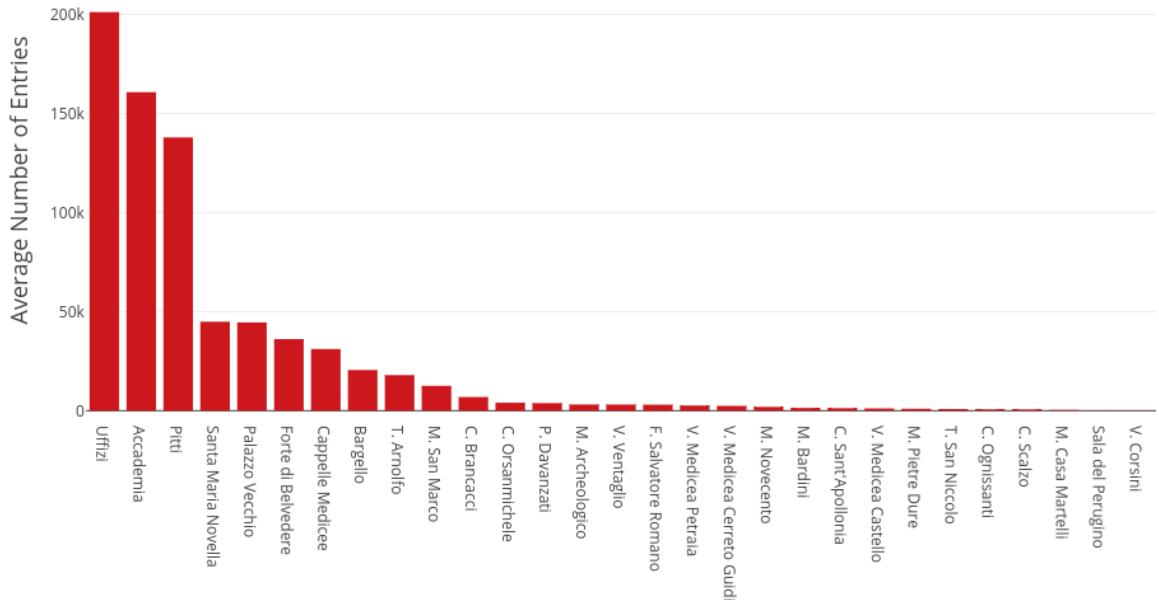


Figure 10. The summer monthly average number of entries at state and national museums for 2016. The top three museums together account for 72.5% of all entries. Note that the Opera del Duomo is not included in the list of national and state museums.

What are the most popular attractions visited with the Firenzecard?

The four top destinations by Firenzecard users are the Duomo (49.899 entries), Uffizi (44.339 entries), Accademia (42.417 entries) and Palazzo Pitti (34.007 entries). These are the same as the top three destinations in the state and national museum data.

Most Popular Museums (June - Sept. 2016)

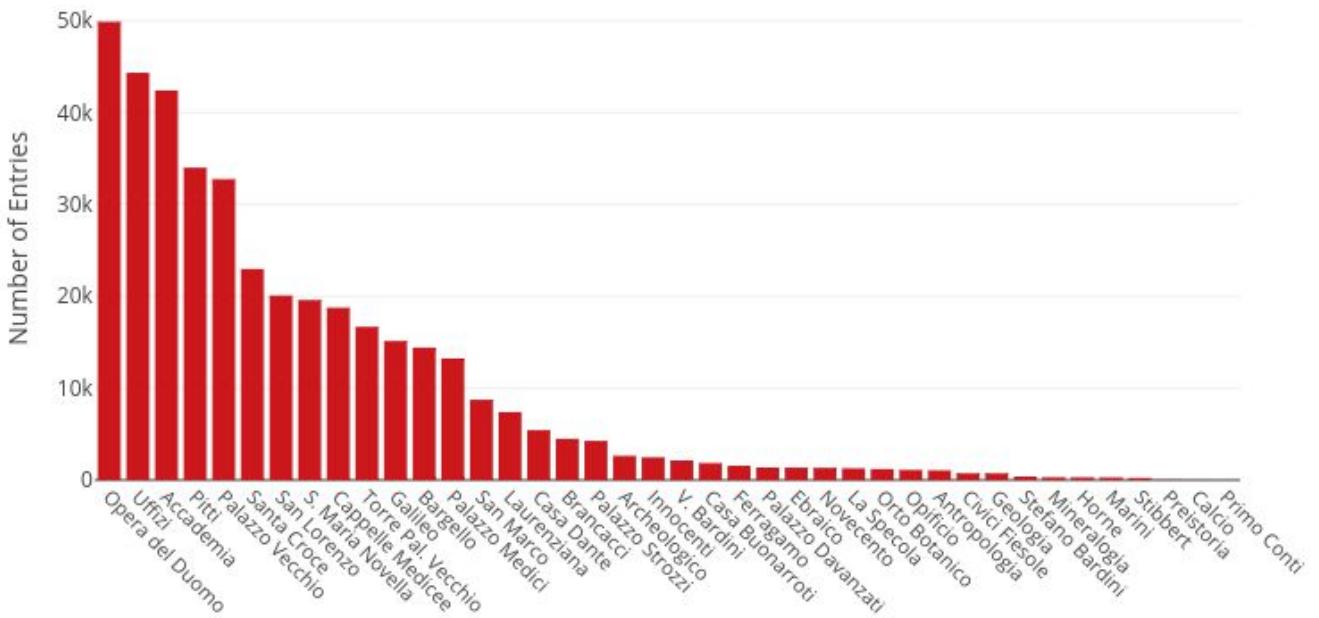


Figure 11. Total number of Firenzecard museum entries over summer 2016.

Number of unique cards visiting the top ten attractions over summer 2016

Museum	Number of cards
Duomo	49.889
Uffizi	44.339
Accademia	42.417
Palazzo Pitti	34.007
Palazzo Vecchio	32.757
Santa Croce	22.979
San Lorenzo	20.086
S. Maria Novella	19.595
Cappelle Medicee	18.759
Torre Pal. Vecchio	16.680

Table 3. Number of cards visiting the top ten attractions on the Firenzecard Circuit for the period of 1st June 2016 through 30th September 2016.

How many different attractions do Firenzecard holders visit?

The most frequent pattern of Firenzecard holders is to visit 6 or 7 attractions. Note that this counts *cards*, not people entering museums; multiple minors may enter on the same card. Counting the number of people, however, results in a similar distribution. This lets us know that most people visit at least two or three places other than the top four attractions.



Figure 12. Number of museums visited with the Firenzecard, summer 2016.

Number of museums visited with the Firenzecard for summer 2016

Number of cards	Number of museums visited	Number of cards	Number of museums visited
1.018	1	4.089	9
2.406	2	3.438	10
4.199	3	2.766	11
5.520	4	2.000	12
5.634	5	1.423	13
5.912	6	916	14
5.527	7	540	15
4.850	8	793	16+

Table 4. The numbers from Figure 12, breaking down how many cards visit how many museums during their activation time. The data is from 1st June 2016 through 30th September 2016.

What is the duration of use of the Firenzecard?

The Firenzecard is active for 72 hours from the validation time, however not all card holders use it for the entirety of the active period. To better understand the behavior of Firenzecard holders, we have calculated how many of these actively use the card for 1 day or less, how many use the card for 1 to 2 days, and how many use it for 2 to 4 days (an afternoon activation will make a Firenzecard last to the morning of the fourth day). Results show that around 50% of card holders use the card for less than the three day period. We learned from the telecom data analysis that the majority of people stay in the city for only 1 or 2 days, and the results from the duration of card use imply that some of these short term visitors still see a benefit in buying the 72 hour card even though their visit to Florence is for a shorter period.

Number of unique cards visiting the top ten attractions over summer 2016

Duration of card use	Number of users	Cumulative number of users
Less or equal to 24h	9.162 (17,9%)	9.162 (17,9%)
24h-48h	17.929 (35,2%)	27.091 (53,0%)
48h-72h	23.939 (46,9%)	51.031 (100%)

Table 5. The breakdown how many cards are active for how many hours. The data is from 1st June 2016 through 30th September 2016.

How many minors enter with adults?

Out of the total of 51.301 Firenzecards, 4.914 are cards with travelling with minors (9,6%). The majority of Firenzecard users are not travelling with children. Knowing how many minors there are at museums in Florence as well as what types of museums these families visit is helpful for knowing which museums seem more or less kid friendly.

Number of minors per museum entry over summer 2016

Minors per Museum Entry	Percentage	Cumulative Percentage
0	92,5%	92,5%
1	5,4%	97,9%
2	1,6%	99,5%
3+	0,5%	100%

Table 6. The breakdown of percentage of Firenzecard entries that include minors. Minors share the same card as an adult. The data is from 1st June 2016 through 30th September 2016.

When do people activate and start using their Firenzecard?

It is important to know when people activate their Firenzecards since the population of users visiting museums with the card will be higher on the days following an activation. Two of the most popular museums to first use a card are the Uffizi and the Accademia. Given that both of those museums are closed on Mondays, we see an expected surge of activations on Tuesday. This has broader implications for the types of people buying Firenzecards; since many users want to use their card to obtain priority entry at the top museums, people are less likely to want to use a Firenzecard if their trip to Florence includes a Monday. Additionally, this large surge in activations on Tuesdays can partially account for the lowered entry rates with the Firenzecard we see on Friday, Saturday, Sunday, and Monday at many museums.

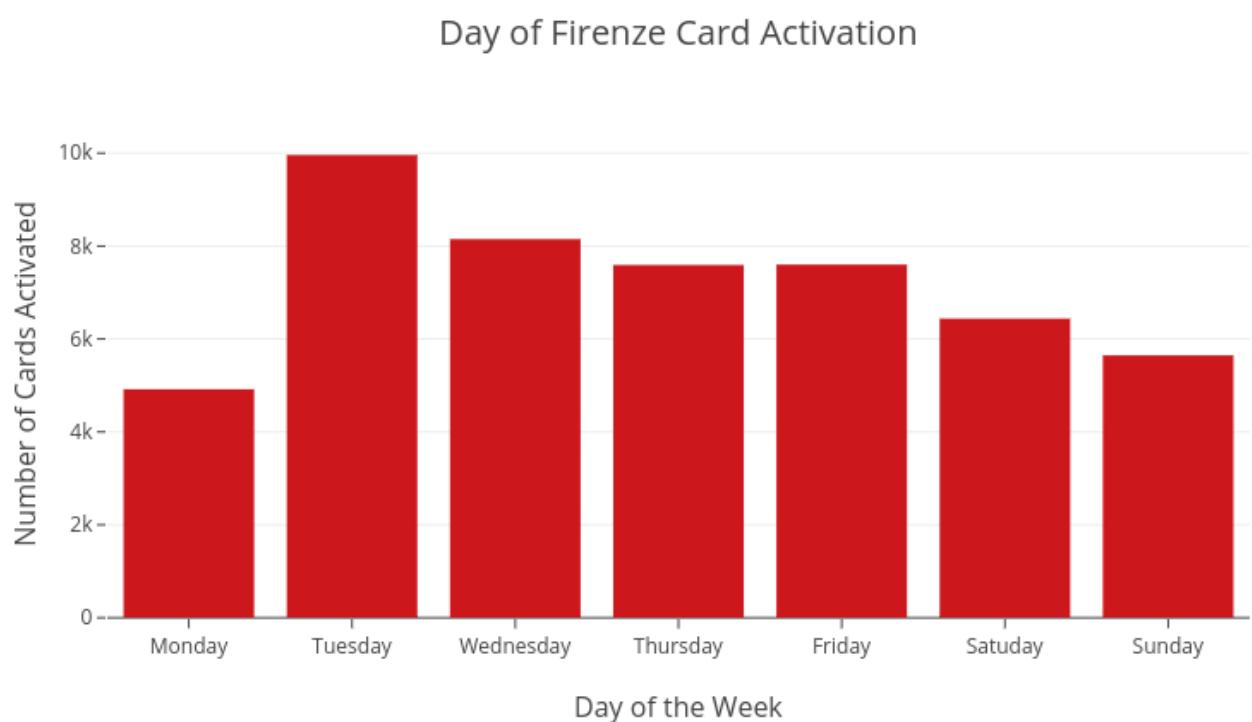


Figure 13. Number of cards activated per day of the week. The data is from 1st June 2016 through 30th September 2016.

Comparison of museum activity

One of the rising issues in Florence is the systematic accumulation of large crowds of tourists at a few major locations (i.e. Uffizi, Accademia, Duomo). To grasp the extent of the crowding situation it is necessary to compare the sizes of crowds at different tourist attractions. Understanding the specific times at which this crowding phenomena occurs and how the sizes of crowds change throughout the day also allows us to gain a more complete understanding of the problem. With this information, we can make recommendations that will be helpful in finding solutions to redistribute people in a more balanced manner across the several museums and surrounding public spaces.

In order to grasp these patterns, we have generated analysis which look at the number of entries in different museums over time, and provides a basis for the comparison of similarities or differences between museum entry activity.

What are the busiest days of summer 2016?

Below are examples of the daily entry activity with the Firenzecard at tourist attractions, showing which days of summer 2016 had the most museum entries. The peak number of entries for Firenzecard holders is in August. We observed in the telecom data (previously mentioned) that the month of August is the lowest point of tourist activity during summer 2016, suggesting that the telecom and Firenzecard datasets do not represent the same types of visitors. One possible explanation is that the Firenzecard might be used more by visitors of certain nationalities. Indeed, the breakdown of presence by nationality of the telecom data indicates that some nationalities visit Florence more than others in August. For example, there is an increase of French visitors in August but a sharp decline of Chinese visitors. This hypothesis could be confirmed by collecting data on the nationality of the Firenzecard holders.

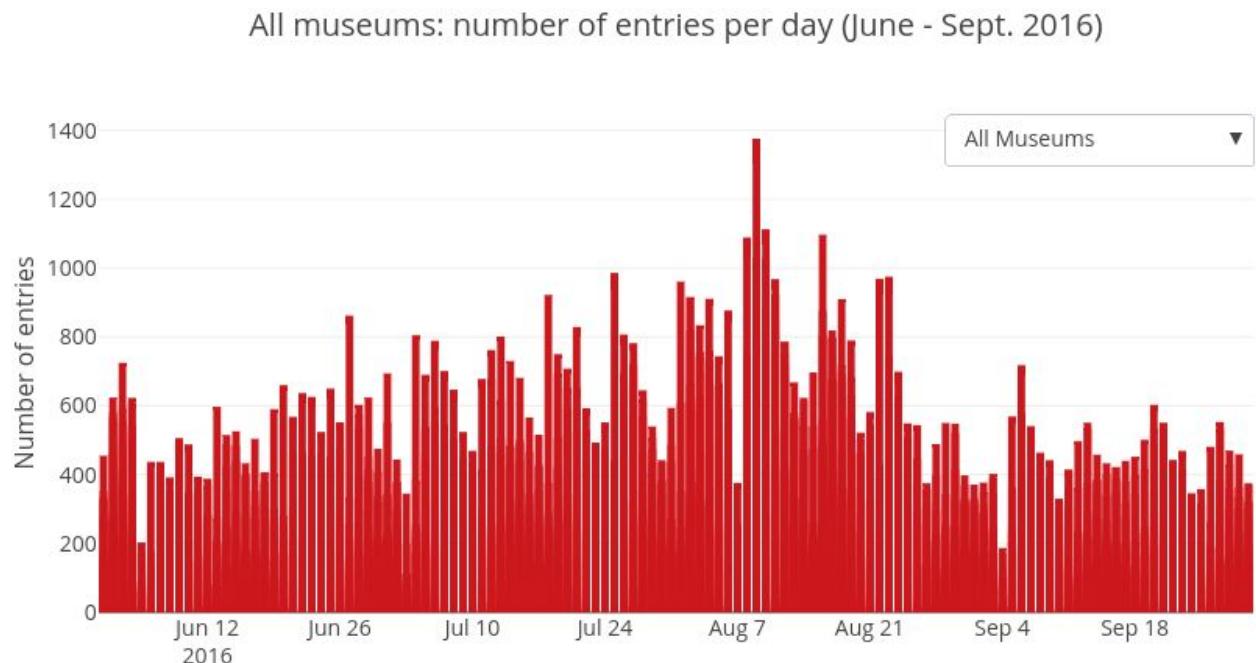


Figure 14. Time series for the number of entries in total to all the museums on the Firenzecard from 1st June 2016 through 30th September 2016.

See appendix Figures B.1–B.4 for individual time series plots for the most popular museums.

What are the busiest days of the week?

Understanding which days of the summer are days of peak tourism activity is crucial to prepare the city for large crowds. However, this information alone is not sufficient. We have also analyzed the busiest days of the week and times of the day, allowing us to see more precisely which museums are full and which are underutilized. Figure 15 suggests that the Monday closure of the Uffizi and the Accademia have a considerable impact on the number of entries to other museums in the city. Wednesday and Thursday are the busiest days in terms of museum entries, which could in part be

due to there being more users with active cards on Tuesdays, Wednesdays and Thursdays than the rest of the days of the week.

Figure 15. Time series for the number of entries in total for each day of the week to all the museum on the Firenzecard from 1st June 2016 through 30th September 2016.

See appendix figures B.5–B.8 for individual weekly time series plots for the most popular museums.

What are the busiest entry times of the day?

It is important to know at what times tourists begin visiting museums as this is an indicator of when the city begins to be busy. From observation of the hourly museum entry time series (Figure 16), we see that starting at 8am, there are already a large number of tourists awake and visiting attractions. This analysis shows us that it is less common to visit museums later in the afternoon and evening. This is due in part to the fact that there are fewer museums open at these times. One would assume that a visitor would not want to enter a museum too close to its closing time.

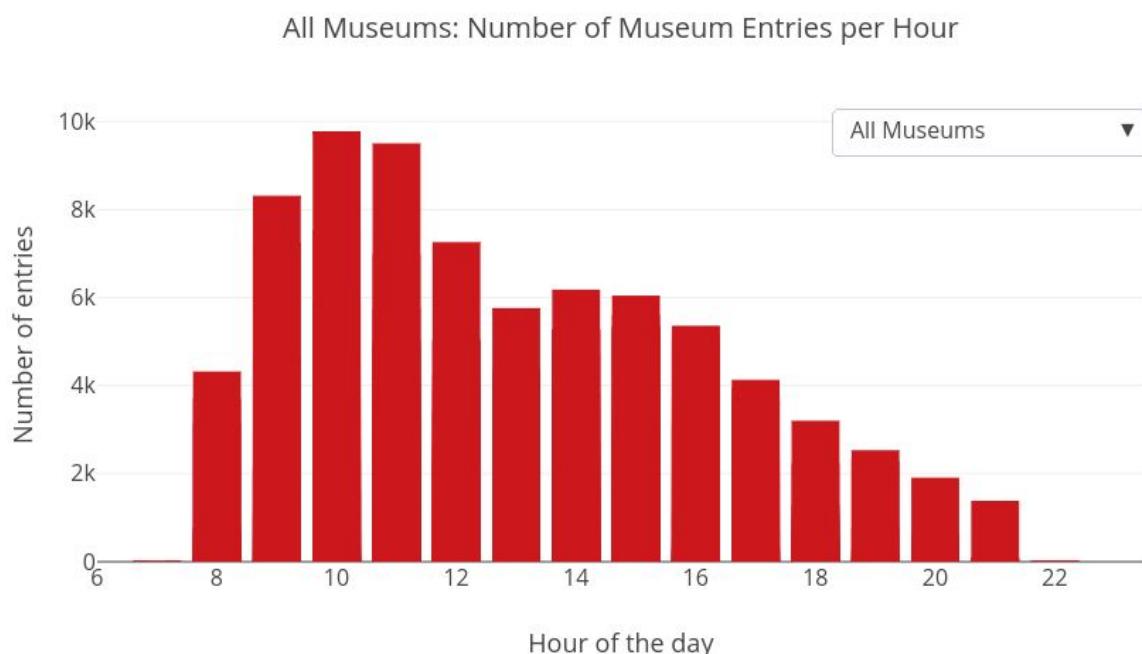


Figure 16. Time series for the number of entries in total for each hour of the day to all the museum on the Firenzecard from 1st June 2016 through 30th September 2016.

See appendix figures B.9–B.12 for individual hourly time series plots for the most popular museums.

Are heavily occupied museums located in close proximity to less crowded museums?

We built a dynamic geographic map which can be used to demonstrate whether at specific hours heavily occupied museums are located close to other museums which are much less busy (without taking into consideration of museum size or maximum capacity). The map allows to click on a specific time (07.00–23.00) and visualize the total number of entries in all Firenzecard Circuit museums open at that hour (June–September 2016). Below are some static map screenshots of visitor museum entry data on Thursday 10th August, at 08.00, 11.00, and 16.00 (a random day of

summer was chosen as an example). As the number of museum entries gradually increases during the day, large differences emerge in crowd sizes between the several tourist attractions. We observe that the same key locations (Duomo, Uffizi, Accademia, Palazzo Pitti) always attract large numbers of people throughout the day, whilst have much fewer entries per hour.

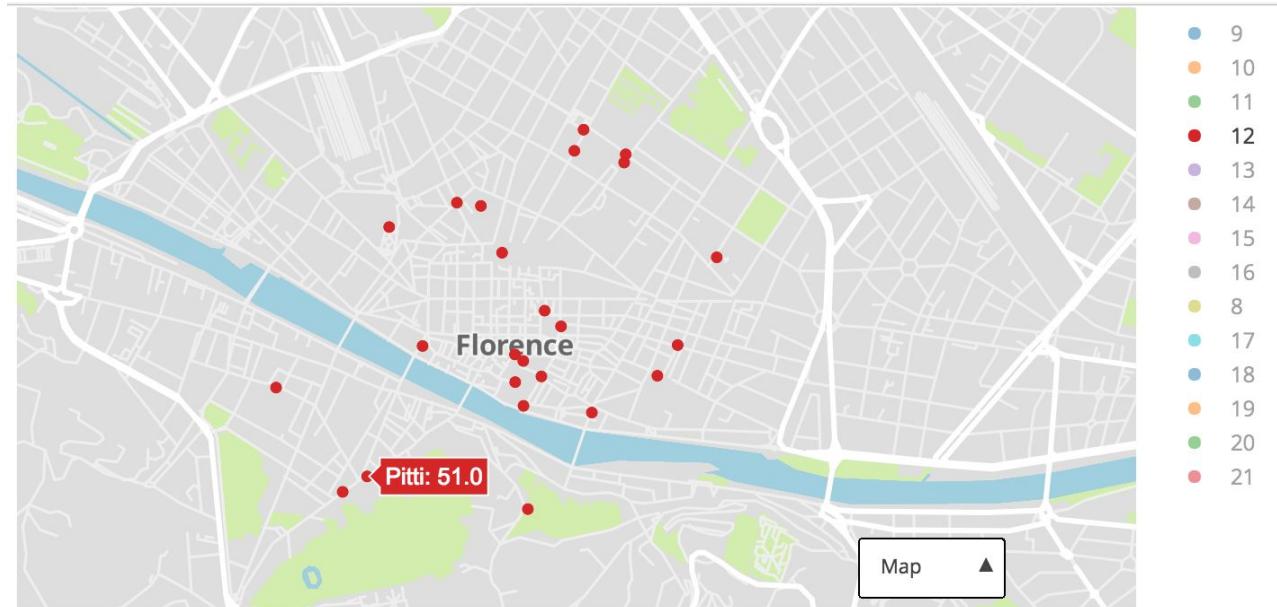


Figure 17. Screenshot of the interactive map of total museum entries per hour of the day (example day: 10th August 2016).



Figure 18. Total entries with Firenzecard, Wednesday 10th August 2016, 08.00.

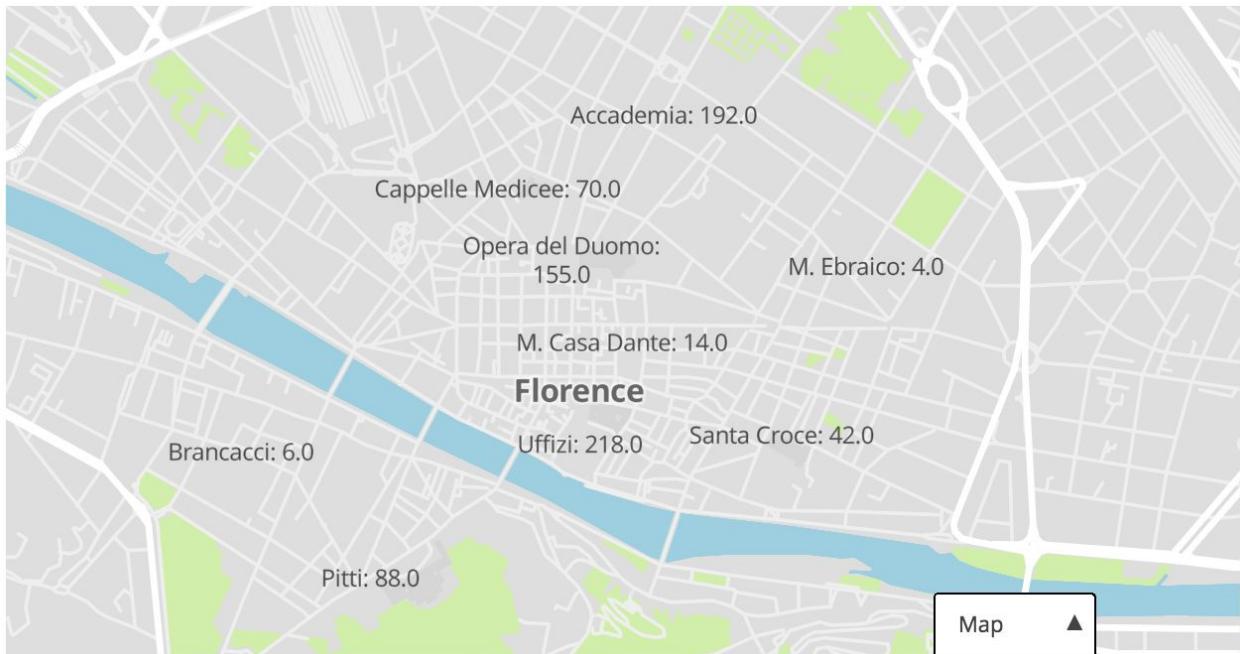


Figure 19. Total entries with Firenzecard, Wednesday 10th August 2016, 11.00.

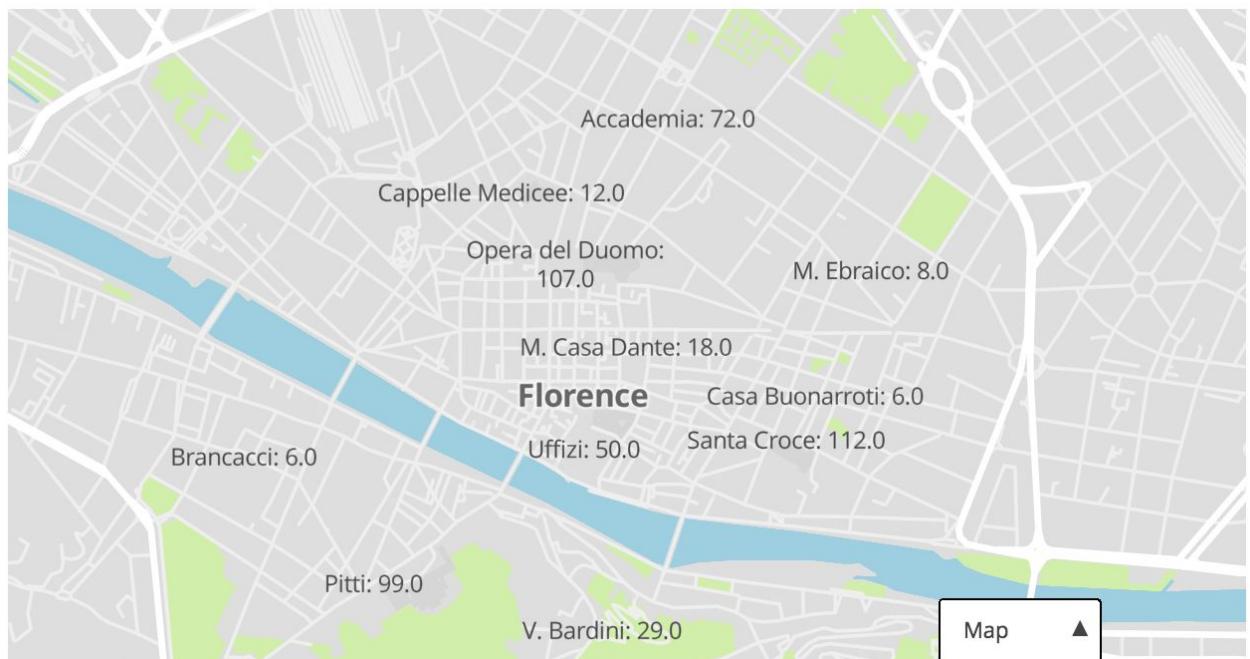


Figure 20. Total entries with Firenzecard, Wednesday 10th August 2016, 16.00.

Patterns of tourist behaviors

The Firenzecard data records the precise minute at which card holders enter museums. This level of resolution is advantageous and necessary for understanding the precise movement of tourists through the city throughout the day. It allows to map the paths of card holders in time and space, as Firenzecard holders move from one museum to another. Knowing the timing and order of visits is extremely valuable information for extracting patterns about flows of visitors within and between

museums, for instance understanding which combinations of museums tourists are interested in visiting. It can also help to estimate the likelihood of crowding of public spaces and streets between museums.

Groups

If several Firenzecards are purchased at the same time, this does not necessarily imply that the card holders are groups of people traveling together. However, if consecutive Firenzecard ID numbers visit the same museums at the same times repetitively, this is strong evidence that the card users travel in groups. This information gives an insight on museum visitor group dynamics. We can also infer whether families may be frequent customers of the Firenzecard, and which museums they prefer to visit, by observing the paths of Firenzecard users traveling with minors. This information is valuable for making targeted recommendations based on group behaviors.

Number of minors per Firenzecard group versus the size of the group over summer 2016

Size of group	Children with group			
	0	1	2	3+
1	22%	2%	<1%	<1%
2	53%	3%	2%	<1%
3+	15%	<1%	<1%	<1%

Table 7. The size of the group versus the number of children with the group.

For this analysis we only considered consecutive Firenzecard id numbers, and our count of 22% of card users being solo travelers is likely an overcount (when looking through the data, we indeed see travelers with identical paths who do not have consecutive id numbers). More careful group identification would likely yield a lower percentage of solo travelers, and higher numbers of groups and larger group sizes. But we are confident in our finding that the majority of Firenzecard usage is by two adults, traveling without children.

Museums visited together

Following this analysis, we checked the most common sets of visited museums. There are an enormous amount of possible sets of museums (specifically, 2^{72}). Only a fraction of those—about 14.000—appear in data, but that is still a lot of variety. Most sets only have 1 or 2 cards who visited those museums, and the most common set of visited museums (Accademia, Opera del Duomo, Uffizi) accounts for only about 2% of all cards. In Figure 21, we see the most frequent sets, as well as the breakdown of in which order they were visited. A given set of museums can be visited in many different orders: for the set of Accademia, Duomo, Uffizi, a cardholder can visit Accademia, then Duomo, then Uffizi all on one day, or Accademia and Duomo on one day and Uffizi the next day, etc. The more museums that exist in a set, the more possible orderings there are, and it turns out that most sets of 4 or more museums do not have any dominant ordering. One exception is the set of Accademia, Duomo, Santa Croce, and Uffizi, where people tend to visit Accademia and Duomo on one day and Uffizi the Santa Croce on the next.

For sets of 3 and 2 museums, surprisingly, the most frequent ordering is always to visit all the museums on one day. Certainly, for any excursionists using the Firenzecard, this is the pattern we would observe, and it is a reasonable assumption that people who cram in multiple museums in one day do so because they are only in Florence for one day. Also suggestive of excursionists is that the fifth most common “set” of visited museums is visiting only the Duomo, and the 14th most common “set” of visited museums being visiting only Uffizi. Spending 72€ to visit only one museum makes sense only if people are putting a premium on skipping lines because they are in Florence for a very short time.



Figure 21. Sets of museums that are visited in common, in order of how common the grouping is. The separators within each bar show the breakdown of the frequency of each ordering of the museums in each set. The data is from 1st June 2016 through 30th September 2016.

Places and relationships between places in terms of sequential co-visitation

Static network visualization

Aggregating to look at flows from one museum to another gives a sense of where to expect to find crowds of people moving through the streets of Florence from one museum to another.

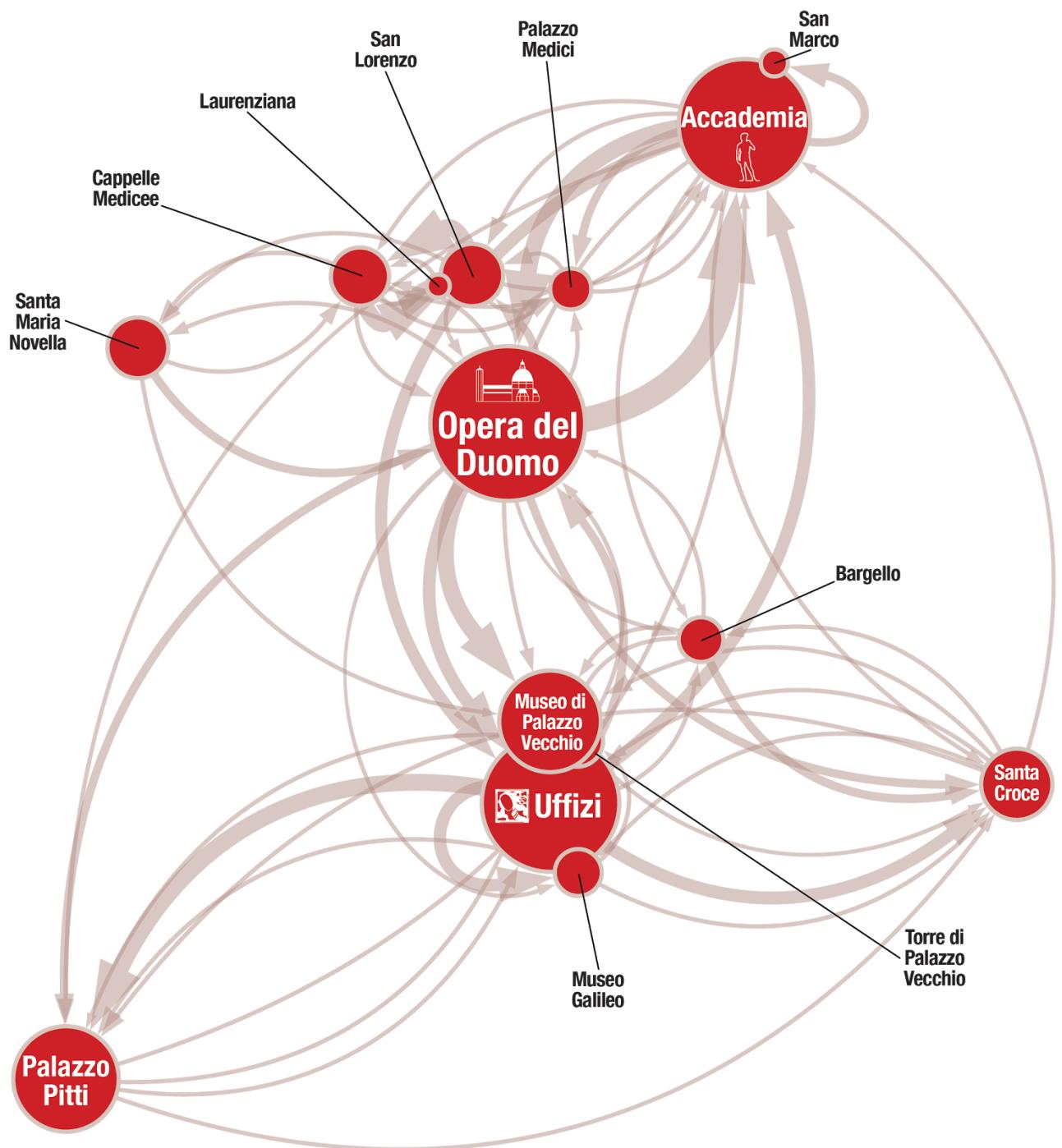


Figure 22. Network of flows between museums. Nodes are proportional to the number of visitors that museums have, and edge widths are proportional to how many people go from one museum to another over the entire period of the summer.

Network Fountain visualisation

We created a fountain visualization for seeing arcs in a network for Firenzecard usage for just one place at a time. Each point on the map represents a Firenzecard location. From every location, we can see arcs that connect it to the next place card users visit and the previous place the user visited. We can see imbalances in flows, such as many more people go from the Uffizi to Palazzo Pitti than vice versa. We also see the effect geographic proximity on visitation of sites. The most commonly

visited next site is not always one nearby, as one might expect. We see that more people start in the center of the city on the northern side of the Arno and go outwards towards Santa Croce and the Oltrarno than the other way around.

The sidebar on the visualization in Figure 23 also shows the total number of Firenzecard visitors to each museum for the duration of the summer as well as the total number of visitors by any means as reported by the museum. Not all of the museums provided data on the total number of visitors, but having that information in the future would give a more complete view on how prevalent Firenzecard usage is at a given museum.

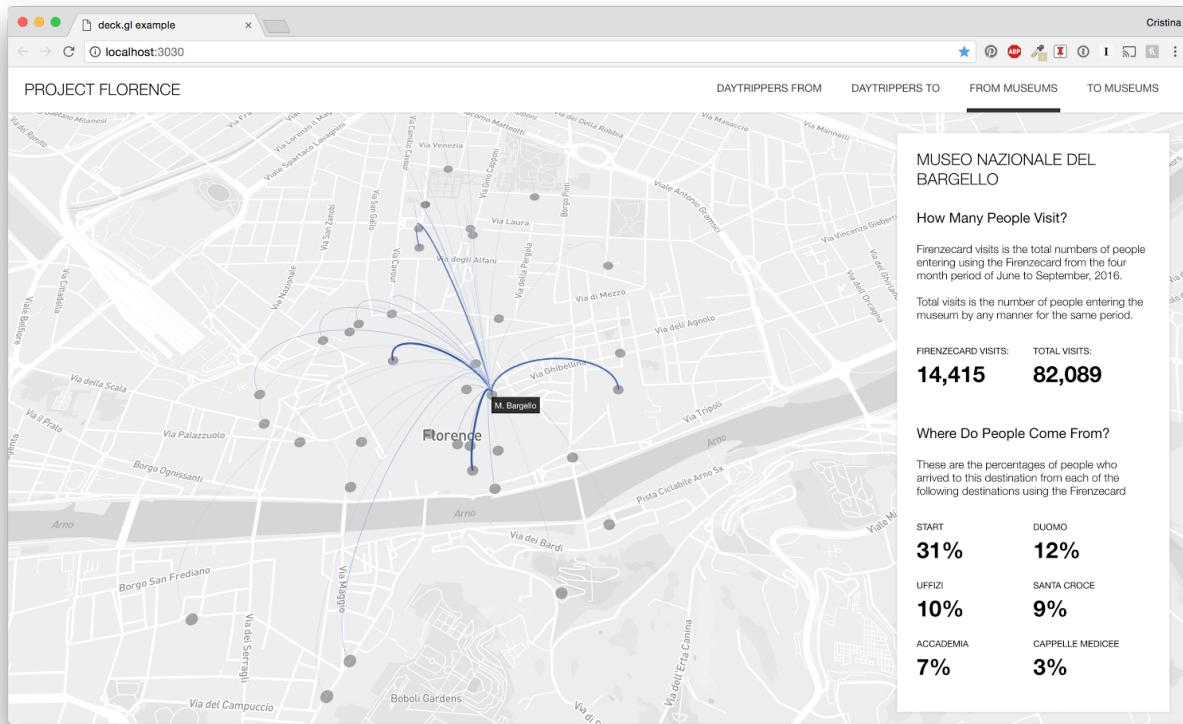


Figure 23. The interactive fountain diagram built to visualize the network of Firenzecard visits during the summer months of 1st June 2016 through 30th September 2016.

Recommendations

Targeted action recommendations

The simplest intervention would be to provide tourists with fixed information at physical sites. Using known patterns of visit frequency, tourists could be informed when lines are longest at museums, so that they can plan to visit at times when the museum is less crowded. Dynamic warning system interventions would be more sophisticated, such as installing notices on screens or on posters that tell visitors about upcoming long waiting times (these would be displayed only at anticipated peak times). Another option would be to build an integration of real-time data into the Firenze mobile

application. Personalized recommendations could be made using the knowledge of sites people have previously visited and where they are currently located. This could be combined with stated preferences to make 1) recommendations for the most relevant and convenient alternative locations to visit while lines are longest and/or crowds are densest at major sites, and 2) planned times at which to return to the sites when they are less crowded.

We can provide more specific recommendations for pairs of museums that experience opposite patterns in visit traffic by looking at pairwise inverse correlations in the time series per day or per hour of museums. Comparing different museum entry data at a given time reveals that one museum may be occupied at full capacity whilst simultaneously other museums nearby are less busy.

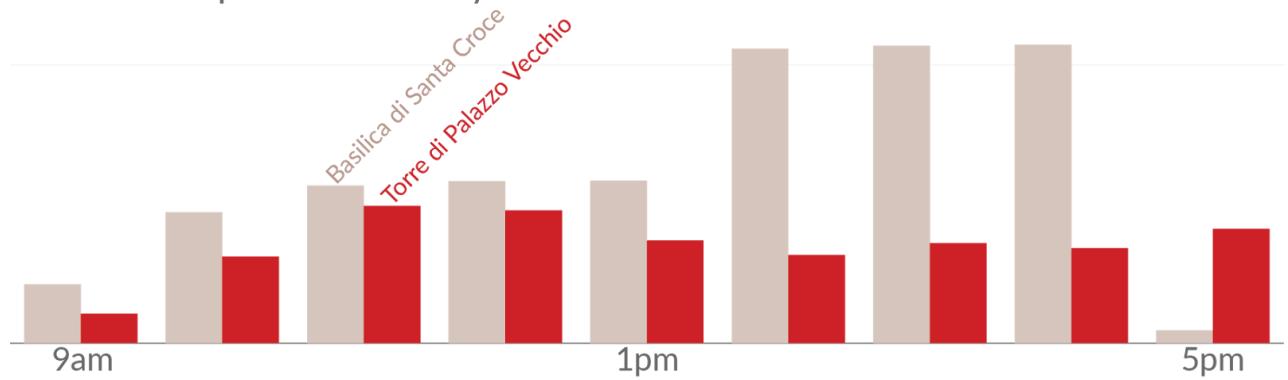


Figure 24. Comparison of hourly Firenzecard total entries over summer 2016 for Basilica di Santa Croce and Torre di Palazzo Vecchio. This comparison suggests a large difference in the sizes of crowds aggregating at museums in the afternoon. Such findings can be used to make recommendations to reduce waiting lines and crowding of streets and public spaces.

One example of this concept is shown in Figure 24. This pairwise time series shows the number of entries to the Basilica di Santa Croce compared with the Torre di Palazzo Vecchio. These two attractions are relatively close, but they experience different surges in traffic. From the network visualization, we see that people are more likely to start in the center of the city and then go eastward towards Santa Croce or South of the Arno toward Palazzo Pitti (Figure 25) than the other way around. One recommendation that emerges from this comparison is that tourists should be encouraged to visit attractions on the outskirts of the city center, such as Santa Croce, first and then make their way back towards the city center.

We additionally recommend that the museums should run experiments with the closing hours of the museums to see the effect of one museum's closure on the other. We see that two of the most visited museums in Florence, the Uffizi and the Accademia, are closed on Mondays. Since both of these museums are already have very high traffic, having a closed day on Monday takes away the ability to distribute crowding into that day. It would provide additional insights to see what happens in the museum visitation patterns if the one closed day for one of those museums shifted to a different day of the week.

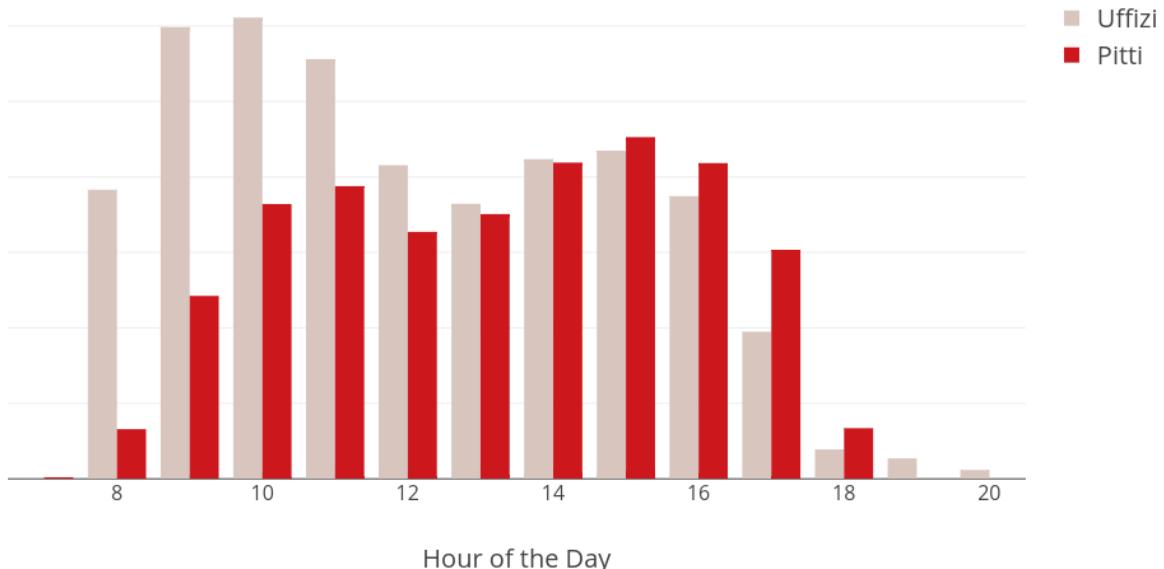


Figure 25. Comparison of hourly Firenzecard total entries over summer 2016 for Galleria degli Uffizi and Palazzo Pitti. This comparison shows that both museums have two peaks of entries, but that the number of entries for Uffizi is larger in the morning than the afternoon and vice a versa for Palazzo Pitti.

Recommendations for data collection

The situation analyses in this report give initial insights on the movements in time and space of a portion (albeit incomplete) of the tourist population in Florence during summer season. The Firenzecard dataset is the highest quality data source for studying the movements of museum and tourist attraction visitors throughout Florence. Combined with the telecom data (which is not as geographically detailed, but covers a far larger portion of Italy), these data sources provide a strong basis to study the movements of crowds throughout the city of Florence.

One additional way to add more geographically detailed information would be to utilize WiFi hotspot data, and collect logs of mobile devices accessing these. While the data would not be as precise as the Firenzecard data to count sizes of groups of people (it is difficult to assess how many people are accessing the internet on a single device), it would provide an estimate of the number of people visiting sites that are not necessarily part of the Firenzecard Circuit.

Mapping the visit behaviors of tourists in Florence allows to better prepare sites to handle increasing numbers of visitors, and dynamically react to crowds (e.g., installing warning notices, or stationing more staff). Each museum is likely aware of its busiest visiting times (day, week, month and year). Implementing a system to communicate this information to the public would give visitors valuable information, allowing them to change their visit behavior in ways that benefit both cultural sites and patrons. If the museums share this data, it can be added to other data sources such as WiFi data to create real-time warning systems that inform when there will be an unexpected increase of visitors at specific sites.

Currently, Firenzecard logs do not keep track of the times at which visitors leave museums. Recording such information would allow to estimate more precisely the number of people inside a museum at a given time. By estimating the number of people in a museum over time, it is possible to make an approximation on the maximum capacity of that museum. This is essential for predicting when touristic areas are likely to become overcrowded and when queues will start to obstruct surrounding streets and squares and would greatly help in making recommendations for which places to avoid at certain times. Obtaining museum visitor exit information would also allow to calculate the average visit duration for specific museums. The difference between entry times, which we have used as a proxy for duration of visit, is not always a good estimate since we cannot know how much of the intervening time was spent in the museum.

Dynamic monitoring systems based on digital trace data such as WiFi access logs or Call Detail Records are useful for longer-term urban planning. As discussed above, these sources of data provide information about the whereabouts of excursionists who come to Florence for less than a day and do not appear in the logs of accommodations data. Knowing how many excursionists there are over longer periods can help cities and regions to allocate infrastructure resources to accommodate these tourists, and create policies that incentivize certain visiting behaviors.

Also worth noting is using water consumption to indirectly estimate tourist numbers (Stefano Rosignoli, Enrico Conti, and Alessandro Viviani, "Local Impact of Tourism: The Case of Tuscany," *Scienze Regionali* 12, no. 3, 2013: 89-110). But water consumption is only accurately measured once a year, not frequent enough to inform quarterly or even annual planning. Still, using telecom data is a direct successor to this kind of work that used an indirect source of data to estimate tourist numbers.

Recommendation systems could be implemented as a Firenze mobile application or internet website. These could be used to survey visitor preferences and accordingly suggest routes that find a compromise between avoiding crowds and minimizing travel time. If sufficiently popular, this system could even plan users' routes, directing groups of people on different itineraries.

In all of these cases, putting in place systems which dynamically measure tourist numbers at different times and places will be necessary. Machine learning systems may assist to generate predictions on how many people will show up at specific places at specific times, however such predictions can be inaccurate, and it is important to constantly test systems to verify if they are performing well. Such monitoring systems would also give feedback for testing effectiveness: for example, checking if enough people follow recommended itineraries for an intervention to have an impact.

It is difficult to quantify in advance how a recommendation system might assist managing the issue of mass tourism in Florence, however we do know that there is an increase in the use of mobile applications and internet services in the tourism sector. People frequently use online services such as TripAdvisor or Yelp when traveling and making choices (e.g. which restaurants to eat at, which locations to visit). People are now used to receiving road directions and recommended travels from services like Google Maps. An online recommendation system or similar warning systems

implemented may assist the city of Florence in reducing crowding of tourists at key areas in a more sustainable way. Such solutions may help to both enhance the quality of the touristic experience and alleviate issues that mass crowding of visitors creates for residents of Florence.

Appendix A: Limitations

Since many of the limitations of our data sources and methods are more technical, we include them here as an appendix.

Call Detail Records

The sampling frame for circuit switching that makes up CDR is highly nonrandom: it samples where people are only when they chose to make (or happen to receive) a call, which we would imagine creates bias towards places where people have leisure to make social calls, or places from where people make logistics calls such as to coordinate meeting up. This is certainly is more sparse than what is needed to give a picture of overall paths of movement for individuals. The geographic resolution is also relatively low, about at the level of neighborhoods rather than at the level of city blocks, as the only geographic data recorded is the location of the tower that received the call, and some towers cover relatively large areas. Additionally, if one region is particularly crowded, towers from a nearby area sometimes pick up the call; there is no record of when this happens since rerouting is done dynamically and automatically within highly optimized telecommunications systems.

However, when aggregated over multiple people, CDR provide a broad overview of volumes of people per region and their movements.

Many non-Italian tourists likely turned off roaming on their phones to not incur fees, or made calls very sparingly during their visit. Activity that does exist may be biased towards business users with companies who cover roaming costs or provide roaming plans. For these tourists, we would have little or no data as compared with Italians. Given the widespread availability of wireless internet, and mobile apps like WhatsApp that allows for voice and video calling over WiFi, people now have the ability to make calls that will not be seen in telecommunications data. However, changes in European roaming agreements since the data collection period in 2016, eliminating roaming charges within the EU, might lead European tourists to use their phones as much in Florence as they would in their home country. Non-EU tourists, however, will still likely have less activity.

Another limitation is that our data only includes calls made on Vodafone's network. Italians who use networks other than Vodafone, and foreigners whose roaming agreements are with companies other than Vodafone, do not appear. We do not know any systematic differences that would cause mobile providers from certain nations to have unbalanced roaming agreements with Vodafone Italy, but it is possible that additional bias is introduced here. The market share of Vodafone Italy ranges from 20-40% for residents of Italy, with more specific estimates at a regional level. These market share estimates were one factor used to scale the CDR data to assess presence for Italian visitors and residents.

Firenzecard

The Firenzecard dataset is a robust source of information for estimating activity of users at museums and attractions in both space and time, but it presents several constraints. Although the card grants access to 72 of the major museums and tourist attractions in Florence, it does not cover

all of the museums and tourist attractions in the city. Of the 72 museums on the card, many already have free entry, so no scan is registered at those locations. Additionally, the card does not record any data of a user's exit from a museum. As a result, the dataset only contains entry information to paid attractions, and only allows us to roughly estimate the amount of time a cardholder spends at a museum. For example, if there is a 3 hour gap between entries, it is not possible to determine if people spent 15 minutes at the museum and then the remaining time eating lunch, or stayed at the museum for 2h45m and then spent 15 minutes traveling to the next museum. Tourist attraction exit information would be valuable to calculate more precisely how many people are in a museum at a given time, and how likely these visitors are to be occupying public spaces in the surroundings.

Appendix B: Supplemental Plots

Opera del Duomo: Number of Museum Entries per Day

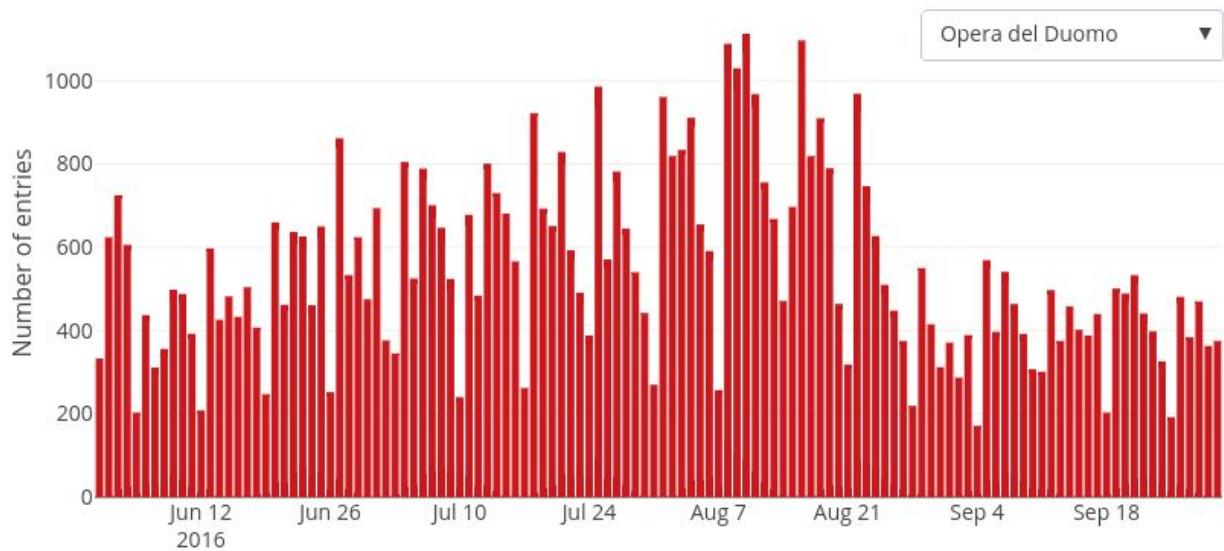


Figure B.1. Time series for the number of entries to the Opera del Duomo with the Firenzecard from 1st June 2016 through 30th September 2016.

Pitti: Number of Museum Entries per Day

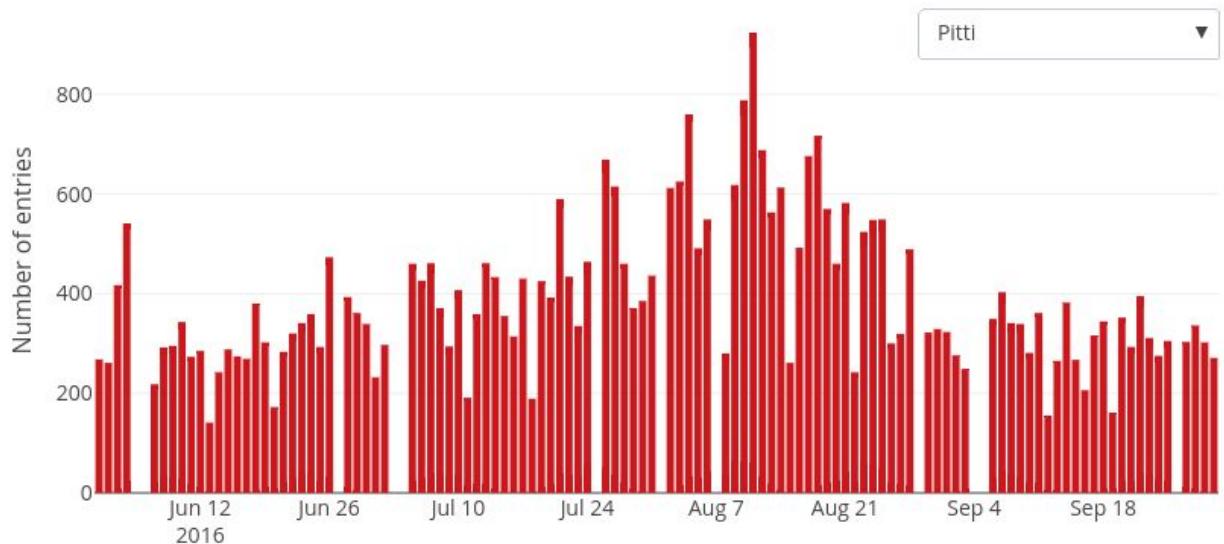


Figure B.2. Time series for the number of entries to the Palazzo Pitti with the Firenzecard from 1st June 2016 through 30th September 2016.

Accademia: Number of Museum Entries per Day

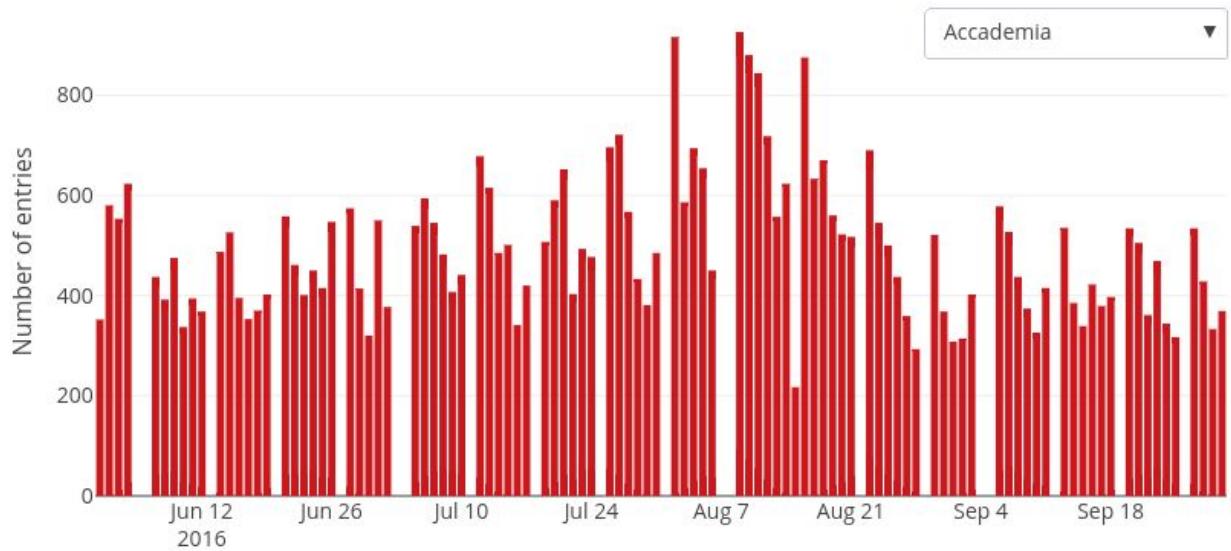


Figure B.3. Time series for the number of entries to the Galleria dell'Accademia with the Firenzecard from 1st June 2016 through 30th September 2016.

Uffizi: Number of Museum Entries per Day

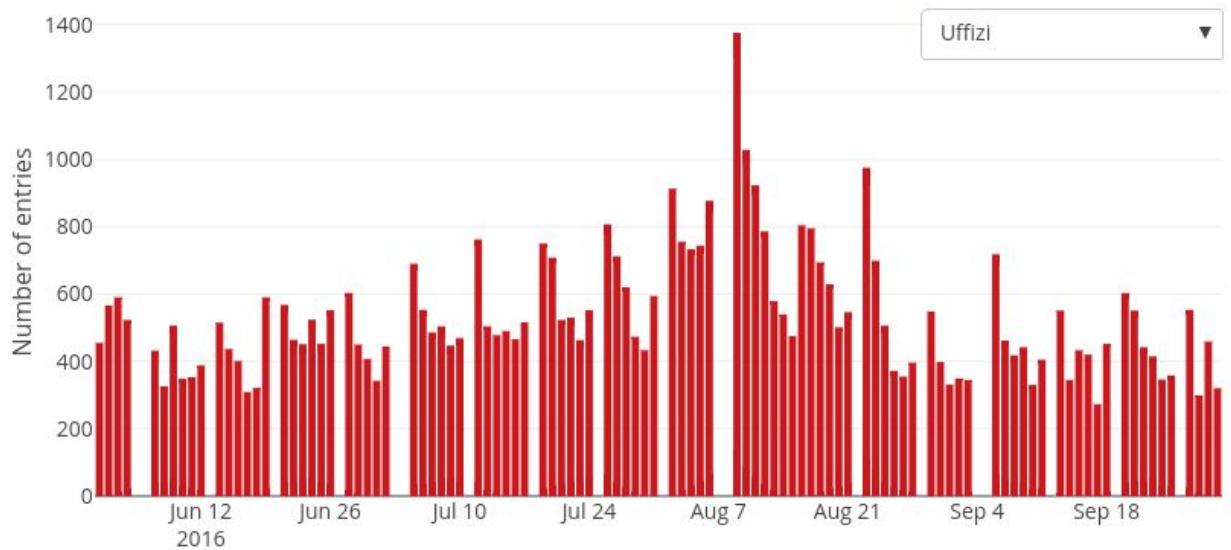


Figure B.4. Time series for the number of entries to the Galleria degli Uffizi with the Firenzecard from 1st June 2016 through 30th September 2016.

Opera del Duomo: Number of Museum Entries per Day of Week

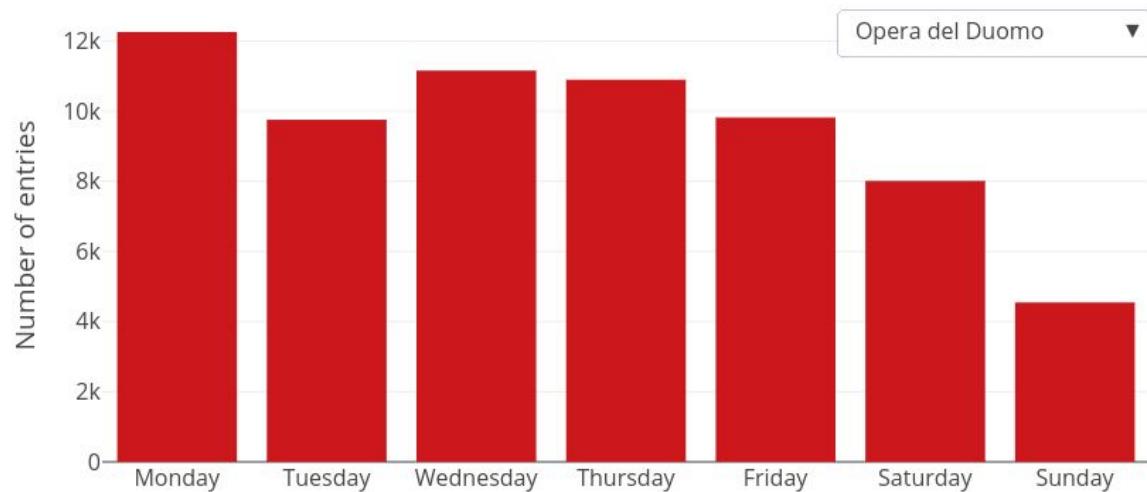


Figure B.5. Time series for the number of entries each day of the week to the Opera del Duomo on the Firenzecard from 1st June 2016 through 30th September 2016.

Pitti: Number of Museum Entries per Day of Week

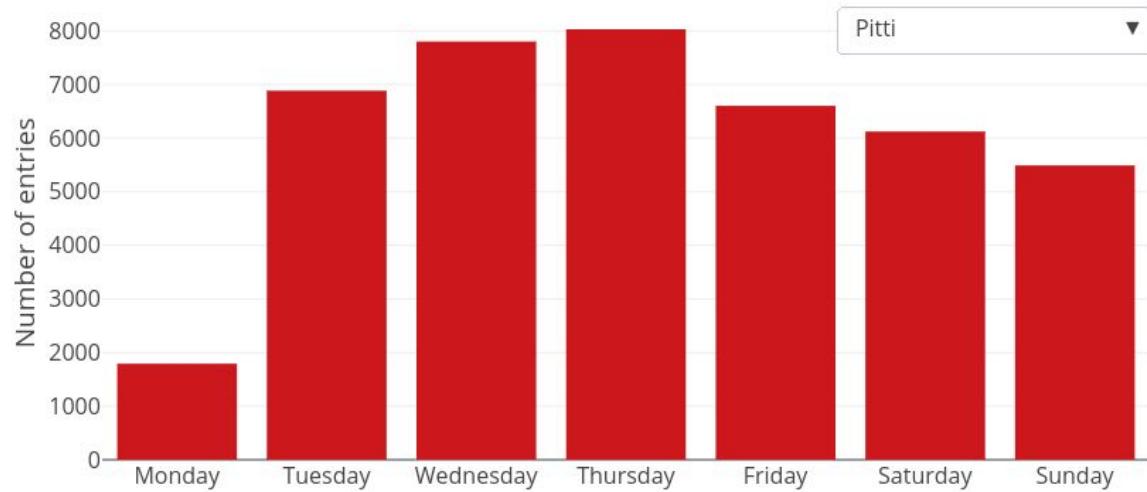


Figure B.6. Time series for the number of entries each day of the week to the Palazzo Pitti on the Firenzecard from 1st June 2016 through 30th September 2016.

Accademia: Number of Museum Entries per Day of Week

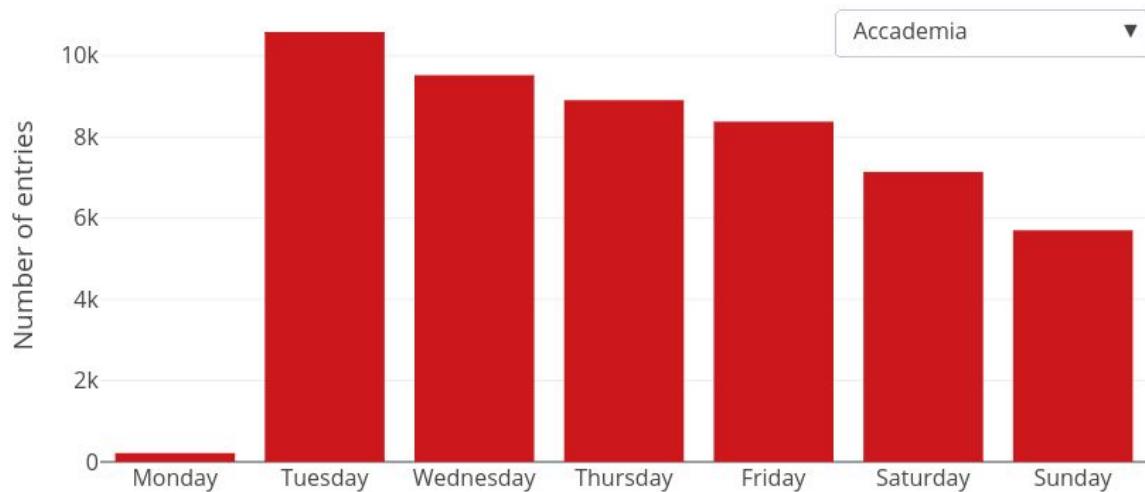


Figure B.7. Time series for the number of entries each day of the week to the Galleria dell'Accademia on the Firenzecard from 1st June 2016 through 30th September 2016.

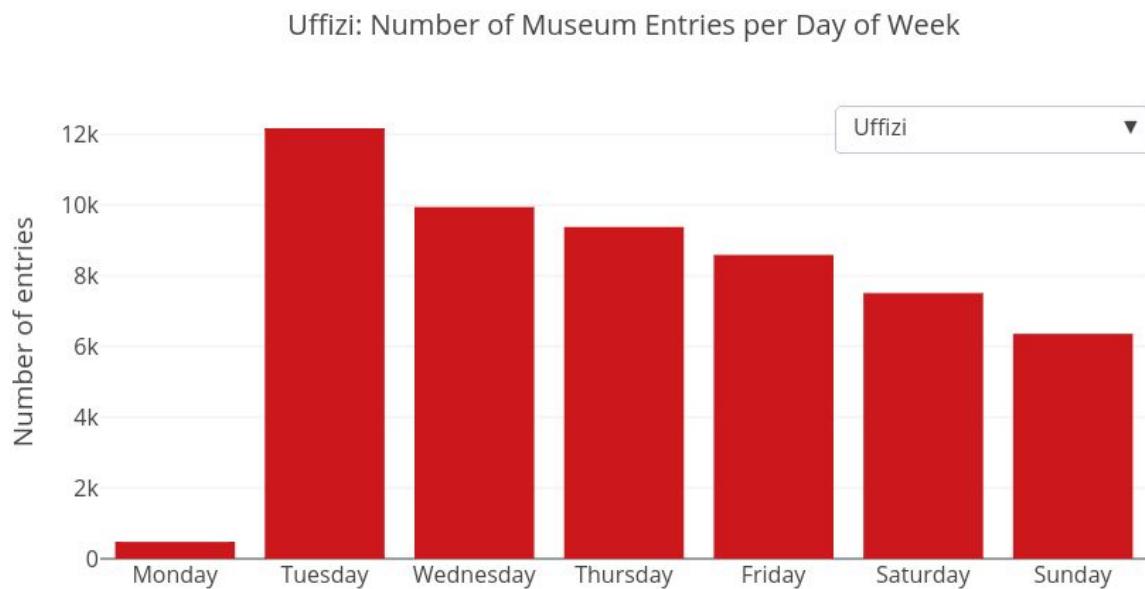


Figure B.8. Time series for the number of entries each day of the week to the Galleria degli Uffizi on the Firenzecard from 1st June 2016 through 30th September 2016.

Opera del Duomo: Number of Museum Entries per Hour

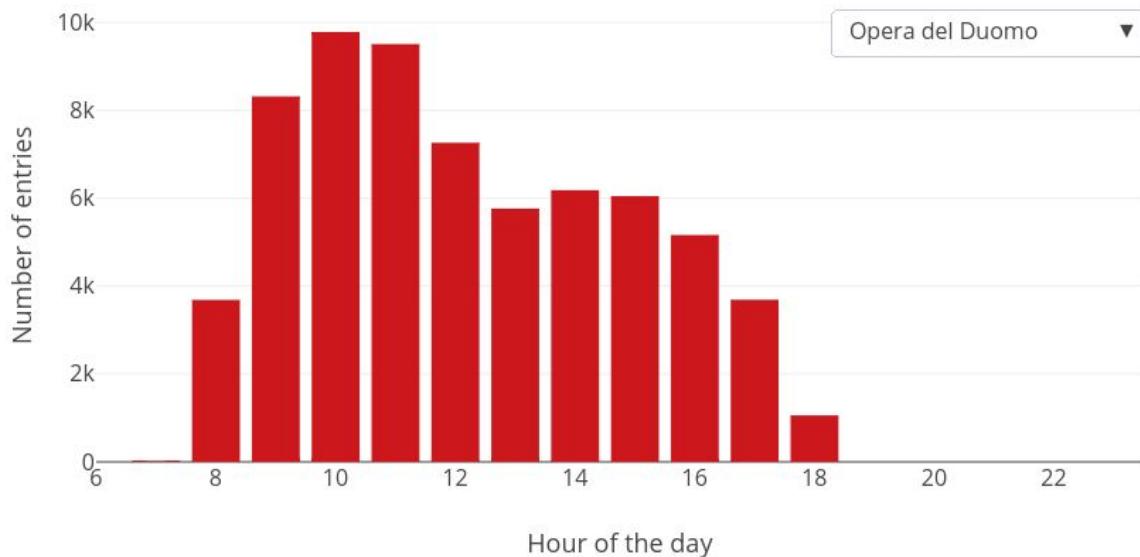


Figure B.9. Time series for the number of entries for each hour of the day to the Opera del Duomo on the Firenzecard from 1st June 2016 through 30th September 2016.

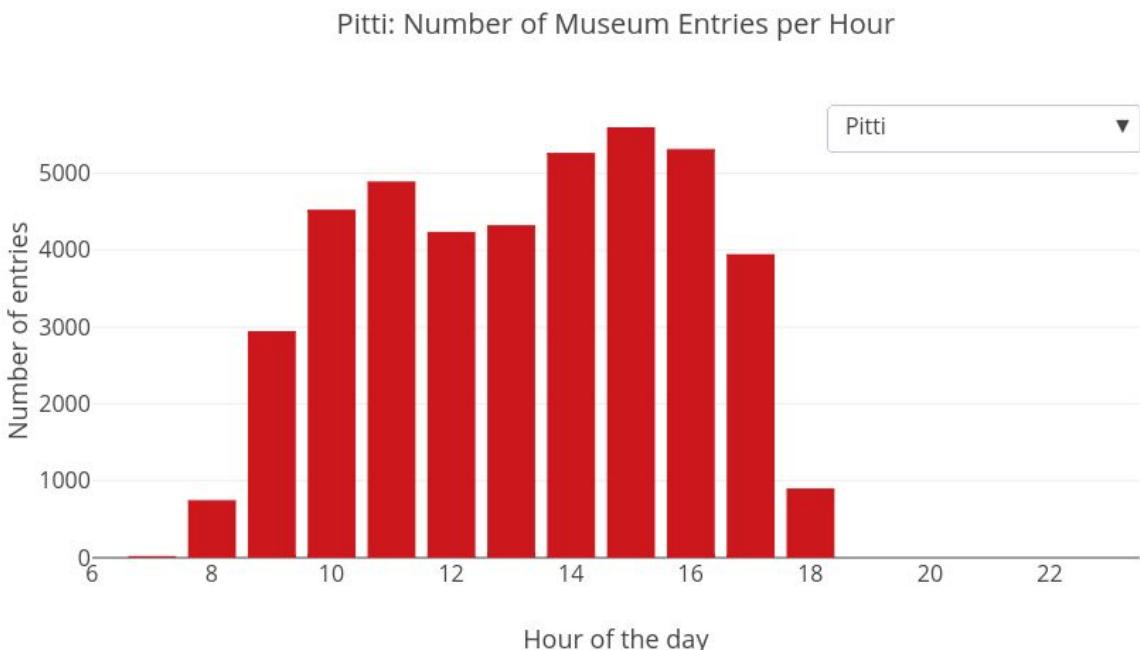


Figure B.10. Time series for the number of entries for each hour of the day to the Palazzo Pitti on the Firenzecard from 1st June 2016 through 30th September 2016.

Accademia: Number of Museum Entries per Hour

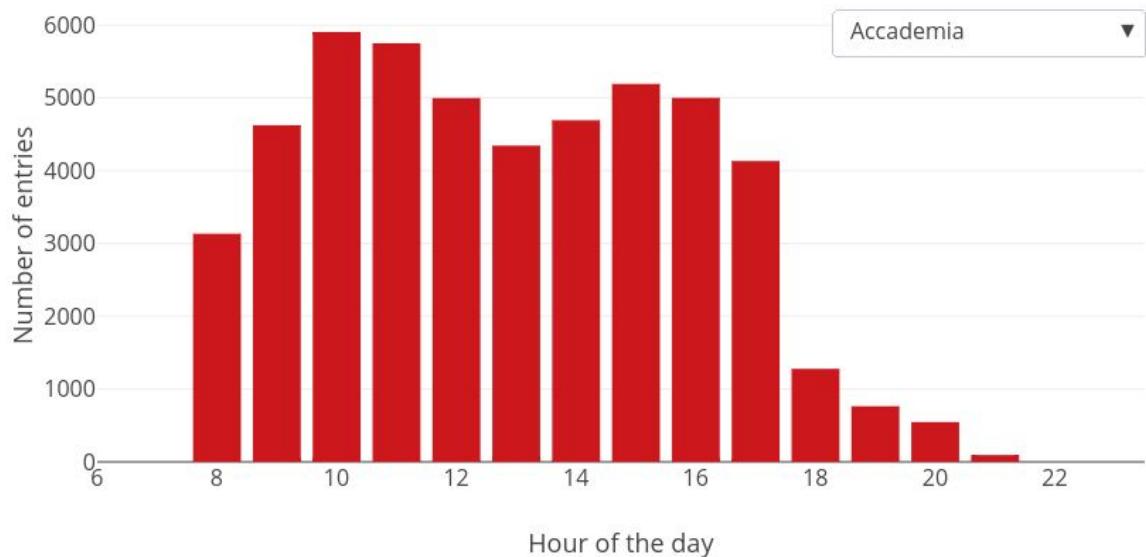


Figure B.11. Time series for the number of entries for each hour of the day to the Galleria dell'Accademia on the Firenzecard from 1st June 2016 through 30th September 2016.

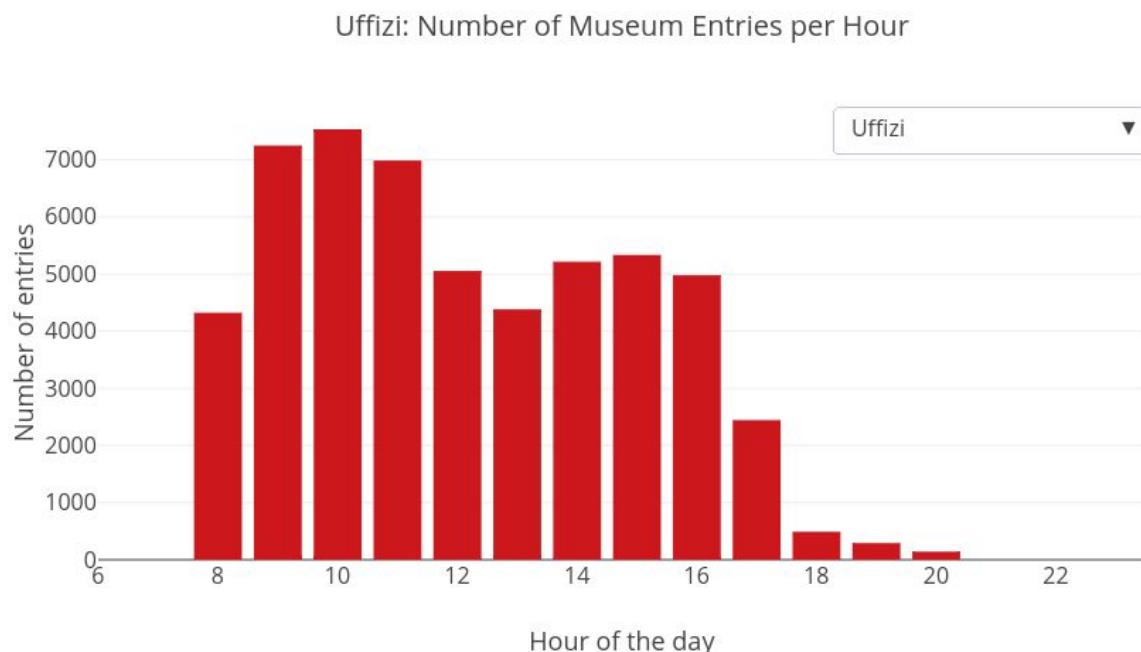


Figure B.12. Time series for the number of entries for each hour of the day to the Galleria degli Uffizi on the Firenzecard from 1st June 2016 through 30th September 2016.