Estimating behavioral changes for transportation modes after terrorist attacks in London, Madrid, and Tokyo

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Disclaimer

Abstract

Why do individuals change their behavior after terrorist attacks? To what extent do changes in risk perception explain changes in travel behavior? This project aims to answer these questions by examining the three major attacks in recent history on public transit systems: the London bombings (July 2005), the Madrid bombings (March 11, 2004), and the Sarin Gas attacks in Tokyo (March 20, 1995). Each case is found to be unique. Reductions in passenger journeys on attacked transportation modes range from an average of 10 percent over 20 weeks in London to no significant change in Tokyo, while substitution to alternative modes also varies across cases. This variance is likely due to more than cultural difference, with primary attack characteristics, transportation system factors, and the social amplification of risk perceptions also playing a role. Such findings have important implications for policy makers and academics with an interest in transportation security and the behavioral and economic impacts of terrorist attacks.

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Comparing behavioral responses to terrorist attacks on public transit systems: London, Madrid, and Tokyo

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Abstract

This section introduces, summarizes, and compares the four studies in this project. Understanding behavioral responses to terrorist attacks on public transit systems is important so that policy makers may better mitigate their economic and human costs. Yet relatively little research exists on the subject due to the significant focus on the impacts of 9/11 as well as the lack of public transit attacks on US soil. To address this shortcoming, the studies in this project examine three major attacks on public transit systems in London, Madrid, and Tokyo. Comparing across these studies, we find unique responses to each attack. For example, passenger journeys on attacked transportation modes were reduced by an average of 10 percent over a period of 20 weeks in London, while no significant change was observed in Tokyo. We explore reasons for this variance, suggesting that primary attack characteristics, transportation system factors, and the social amplification of risk perceptions appear to play a role.

Introduction

Public transit systems are a common target for terrorist attacks worldwide. Their attractiveness as a target for attack is obvious. Primarily, transit systems carry large numbers of individuals in confined spaces, providing the opportunity for terrorists to kill many people with low-cost weapons. Moreover, most transit modes feature low-security vehicles that are also vulnerable – for example, they do not have shock-resistant structures. Finally, public transit systems often sit at the heart of broader transportation and economic networks. Disrupting a transit system can therefore cause substantial harms to a region's economy.

The immediate impact of terrorist attacks on public transit systems is both horrific and well documented, yet the so-called "secondary" impacts are less known. Public transit systems were attacked 182 times worldwide between 1997 and 2000, with 37 percent of attacks involving fatalities, a far higher proportion than terrorist incidents in general (Jenkins, 2004). The human toll of these fatal attacks is significant, with 10 or more fatalities occurring in 28 percent (Jenkins, 2004). As evidenced by our case studies, deadly attacks on public transit systems have occurred both before and since that period. In contrast, neither the cost of property damage caused by these attacks, nor the "secondary" economic and human costs, has been documented. This lack of research provides the impetus for this project.

There is some research into "secondary" behavioral responses to terrorism attacks on transportation systems more generally, yet little on public transit systems specifically. This is unsurprising give the substantial effort to understand the impacts of the attacks on airlines on September 11th 2001, as well as the lack of attacks on public transit systems in the US. Yet the high incidence of attacks worldwide, along with the potential for significant economic impact – transit systems provided over 9 billion passenger journeys per year at the turn of the last decade (Guerrero, 2002) – means that academics and policymakers alike should be concerned with this issue area.

Social psychologist Gerd Geigerenzer (2004, 2006) provides a useful conceptual framework – the "dread hypothesis" – with which to understand behavioral responses to terrorism attacks on transportation systems in general. The "dread hypothesis" comprises three connected stages. The first stage is "dread avoidance," reflected in a reduction in passenger journeys on the attacked transportation mode. The second stage "substitution," is shown by an increased use of alternative, non-attacked transportation modes. There is a critical assumption underlying these first two stages: The reduction in passenger journeys is the result of demand side changes in risk perception, and not due to other influential demand (economic wealth, prices, e.g.) or supply (service provision, congestion) variables for attacked and substitution modes alike. The dynamics of this process – that is the interactions of these other supply and demand variables – is also important to consider. For example, reductions due to fear may be underestimated if they are offset by an uptake in ridership due to reduced congestion. The third stage is an increase in fatalities which result from this substitution, implying that the substitution transportation mode has higher fatality rates than the attacked mode.

In terms of the first stage, numerous studies have identified reductions in passenger journeys following terrorist attacks. In recent years there has been a particular focus on responses to the the September 11th 2001 attacks (Gigenrenzer, 2004, 2006; Blalock, Kadiyali, & Simon, 2005; Sivak and Flanagan, 2003; Ito and Lee, 2005; Beeler Asay & Clemens, 2008; Gordon et al, 2007) with an estimated overall reduction in passenger journeys of 6 percent over 2 years. In their study of Israel, Becker and Rubinstein (2004) estimate that an attack is likely to reduce the number of bus passenger journeys by around 30 percent during the 2 months following an attack, while López-Rousseau (2005) obverses a reduction of 4-6 percent for the 2 months following the 2003 Madrid attacks It is important to note that these studies employ varying degrees of sophistication in modeling this process, as discussed further in the study by Prager and colleagues below. Nonetheless, López-Rousseau (2005), reflecting on the findings in all three cases, suggests, "avoiding a dread risk [the fear of an event occurring] is a universal effect."

In contrast, studies of the second and third stages provide conflicting results in different contexts. Here Gigenrenzer (2006) and Blalock, Kadiyali, and Simon (2005) find that US residents shifted transportation mode from airlines to private road vehicles. Sivak and Flanagan (2003) and Gigenrenzer (2006) show respectively the two elements of the third "dread hypothesis," that the substitute mode is more risky in terms of fatalities, and that fatalities increase as a result of the transportation mode shift. Indeed, the latter estimates that some 1,500 additional individuals died in the US as a result of this mode shift, highlighting the potential human cost of secondary impacts. However, unlike the US, López-Rousseau (2005) finds no increase in alternative modes of transportation. In turn, there was no increase in accidents or fatalities on these other modes following the attacks. In the Israel case, Becker and Rubinstein (2004) find evidence of shifts to alternative transportation modes is found, with increases in taxi passenger journeys in particular. However, they did not examine the fatality element of the "dread hypothesis" framework.

It is important to examine the psychological dimensions of this "dread hypothesis." A key theoretical point in the literature on behavioral responses to risky events such as terrorism is the focus on risk perception as opposed to the statistical likelihood of that event. What may appear to the statistician as "irrational," or the neglecting of calculable probabilities (Sunstein, 2003), is instead individuals responding to what they perceive to be the threat. Such risk perceptions are emotional rather than calculated – they are subject to worry (Sjoberg, 1998) or dread (Fischhoff et al, 1978; Slovic 1987) – they are dynamic rather than fixed, they are subjective rather than objective, and most importantly, they are socially amplified (Kasperson, Renn, Slovic, Brown, Emel, Goble, Kasperson, & Ratick, 1988; Kasperson, 1992; Kasperson, Kasperson, Pidgeon, and Slovic, 2003). A fully developed conceptual framework for the social amplification of risk is presented in Kasperson et al (2003), which usefully incorporates the interrelating and dynamic influences of various government and media agencies, cultural and social norms and values, and personal social networks.

A second theoretical point is that individual behavior in response to risk perceptions can vary. Lerner et al (2003) provide a comprehensive presentation of academic literature on this subject. A key finding here is that individual perceptions of terrorist events associated with anger are likely to be met with behavioral responses of "certainty and individual control," while individual perceptions of terrorist events associated with fear are likely to be met with behavioral responses of "pessimistic estimates and risk averse choices" (Lerner et al, 2003).

Case studies: Summary of papers

Exploring reductions in London Underground passenger journeys following the July 2005 bombings

Prager, Beeler Asay, Lee, and von Winterfeldt use a multivariate time-series regression model to examine the impact of the London July 2005 bombings on London Underground passenger journeys. They find an estimated reduction of 22.5 million fewer passenger journeys over the 4 months following the attacks. Our analysis suggests that heightened risk perceptions are a significant cause of reduced Underground travel, accounting for around 82 percent of passenger journey reductions following the attacks. Lines affected by the bombings appear to have experienced particularly high reductions in passenger journeys. The data also suggests that passenger journeys following the attacks were reduced to a greater extent at weekends and holidays compared with weekdays. This is notable because the majority of travel on weekdays is for work and education, while the majority of travel on weekends is for shopping and leisure trips. Their estimations thus suggest an extra impact for the central London retail and tourism economy.

Prager, Beeler Asay, Lee, and von Winterfeldt's estimates control for both demand (such as demographic, economic, and weather) and supply (station closures, service disruption, time delays) variables. The combination of controlling for these factors, along with the period of reduction extending beyond the reopening of stations after repairs, suggests that changing risk perceptions played a role in the reduction of passenger journeys following the attacks. This finding is supported by survey data (Goodwin et al, 2005; Rubin et al, 2005, Rubin et al, 2007) which shows that 19 percent of respondents reported traveling less as a result of the attacks. Aggregate data limits the ability for close inspection of this issue, such as whether particular social groups were more likely to choose not to travel by the Underground, or which transport modes individuals switched to.

A study of the impact of the July bombings on Londoners' travel behavior

Fasolo, Ni, and Phillips use the "dread hypothesis" model employed by both Gigenrenzer (2004, 2006) and López-Rousseau (2005) to study the impact of the London July 2005 bombings on passenger behavior. They find that Londoners' responses to the July 2005 bombings were distinct from both US and Spain resident's reactions to the respective attacks. In line with US and Spain residents, Londoners appear to have avoided attacked modes – buses as well as Underground. Like US residents, Londoners increased their use of alternative modes, in this case pedal cycles and powered-2-wheelers. However, like the Spain case there is no evidence of increased fatality rates in London.

Fasolo, Ni, and Phillips explore empirically a number of explanations for these unique results. They rule out the suggestion that that substitute modes were less risky than attacked mode by showing that per kilometer risk is higher for the former. They also reject the argument that fatalities in London were focused around the area of the attacks by examining the spatial spread of fatality rates. Moreover, they examine accident rates and find they did not increase either.

Analysis of passengers' reactions to the sarin gas attacks in Tokyo

Prager, Fasolo and Ni use monthly Tokyo subway passenger data to study the impact of the March 1995 sarin gas attacks in which 12 died. They employ univariate time series regression analysis to explore whether the first step of the "dread hypothesis" is correct. Though a slight reduction below predicted levels is observed, this is deemed insufficient to reject the alternative hypothesis that no reductions in passengers journeys was experienced following the attacks. This finding stands Tokyo in contrast with the behavioral responses of US, Spain, and London residents, and implicitly rules out the potential for secondary impacts relating to transportation use.

Prager, Fasolo, and Ni explore a number of reasons for these distinct findings. On the one hand, the absence of a significant change in the use of the attacked mode is explainable due to the limited transportation alternatives, the relatively low number of deaths resulting from the attacks, especially when compared with the 6,000 plus deaths experienced in the Kobe, Japan earthquake two months earlier, and the limited service disruption given the lack of damage to subway infrastructure. It may also be that reductions due to fear were offset by an uptake in ridership due to reduced congestion. On the other hand, this distinct finding is surprising given the relatively slow response of the Japanese government, especially in arresting and convicting culprits, subsequent attacks, and perhaps most importantly, the unprecedented nature of the attacks.

The impact of the 3/11 Madrid bombings on consumers travel behavior

Baumert develops the López-Rousseau (2005) study of Madrilenian reactions to the 3/11 bombings. He presents bus and metro passenger journey data to complement the train and car passenger and fatality data highlighted by López-Rousseau. This is an important development because the transportation patterns within Madrid have not previously been examined. Baumert finds that both buses and metro operators experience a single day drop in passenger journeys on the day of the attacks, with figures bouncing back following the attacks. Unfortunately, passenger journey data for the short-distance inter-urban trains directly affected by the attacks is unavailable.

Baumert suggests that, in line with López-Rousseau, the Spanish resident responses to the 3/11 attacks are tempered relative to the US and London cases due to the decades-long history of terrorism on Spanish soil. Moreover, the relatively limited size of attack and smaller "car culture" compared with the US mitigated transportation behavior impacts compared with the September 11th 2001 aftermath. In terms of Madrid intra-urban transportation substitutes data, it seems that only a short-term impact occurred, suggesting that where passengers did move away from the inter-urban train system – as shown by López-Rousseau – they moved neither to cars nor to the metro or bus systems. This would suggest that passengers decided not to travel rather than choose alternative modes.

Comparison of cases: London, Madrid, and Tokyo

The first key theoretical finding is that transportation behavioral responses to terrorist attacks are far from uniform. In particular, the Tokyo case suggests the "dread risk" avoidance is not "universal" as López-Rousseau (2005: 427) suggests. If true, this raises important questions. Why have public responses to these attacks appeared to differ between cases and countries? What variables distinguish these cases? In order to examine the case studies in a coherent manner, it is important to develop a framework for analysis based upon current theory on behavioral responses to terrorist attacks.

We suggest a tentative framework for analysis. This builds upon the binary primary/secondary impact model of hazardous events proposed by Kasperson (1992) and the social amplification model of risk model proposed by Kasperson et al (1988). Primary impacts are those direct results of the hazardous event, such as lives lost, traumas induces, structures destroyed and infrastructures damaged. Secondary impacts are those hazardous event impacts which "extend beyond the people directly affected by the original hazard event or report" (Kasperson, 1992: 160).

Table 1: Comparison of dread hypothesis results across cases

Location, Date (mode and method of attack)	Dread hypothesis stages		
	Change in aggregate attacked mode passenger journeys	Change in alternative mode use	Change in alternative mode fatalities and accidents
Tokyo, Japan, March 20th 1995 (subway, Sarin gas)	No significant reductions (Prager, Fasolo, & Ni, below)	No change (implied)	No change (implied)
US, September 11th 2001 (airlines, crash into buildings)	6% average reduction over two years (Gordon et al, 2007)	Increase in private road vehicles	1,500 additional road deaths
Madrid, Spain, March11th 2004 (train, bombs)	5% average reduction over two month (López-Rousseau, 2005)	No significant increase in road use (López-Rousseau, 2005). Single day reduction in buses and metro (Baumert, below).	No change (implied)
London, UK, July 7th 2005 (subway and bus, bombs)	8.3% average reduction over 4 months (Prager et al, below)	Increase in pedal cycle and two-wheeler use (Fasolo, Ni, & Phillips, below).	No significant increase in fatality or accident rates across alternative modes and localities (Fasolo, Ni, & Phillips, below)

Primary attack characteristics

The first set of variables likely to influence public transportation choices following terrorist attacks is primary attack characteristics such as the method, size, scope and location of the attacks, as well as the impacts of the attack, such as the number of deaths, injuries, and the damage caused. For example, a large, coordinated attack on numerous points in a transportation system would likely result in greater reductions in passenger journeys for that mode when compared with a relatively minor attack. However, this set of variables is only manifested through the following sets of variables, the transportation system factors and social amplification factors.

Transportation system factors

First, the primary attack characteristics are filtered through transportation system factors. These include the extent of damage relative to size of the system, the difficulty to repair any damage, the number of points damaged, and the flexibility of the system in terms of alternative routes. The key variable here is the cuts in service, which result from damage done and contribute to reductions in passenger journeys for the attacked mode. A clear distinction here is between the sarin gas attacks of Tokyo and the bombings on the Madrid rail and London Underground systems. The lack of infrastructural damage caused by the chemical attacks meant that the Teito Rapid Transit Authority was able to resume service quickly following the attacks. This stands in contrast to the London case where full service was not resumed for a month following the attacks.

Transport mode substitutability within the broader transportation system of the urban area appears to be important also. The ability of individuals to switch to other forms of transport to avoid the "dread risk" of the attacked mode appears to influence the change in passenger journeys following the attacks. For example, the lack of reduction in passenger journeys in the Tokyo case are likely to have been influenced by the inflexibility of the broader system to cope with alternative routes. In contrast, the relative high flexibility in the US transportation system enabled individuals to take alternative modes. A lack of flexibility in the broader system would make the change in passenger numbers more reactive to the time taken to repair damage in the system. The relationship between transportation modes is also a factor, particularly in reference to travel time and service quality. Of course, the communications technology revolution of the past few decades has enabled a growing flexibility in transportation choices, such as the ability to work from home or shop online.

Social amplification

The complex nature of social amplification, as discussed above and in Kasperson et al (2003), constrains precise identification of influencing variables. However, there are some elements of social amplification which appear to have influenced the transportation behavior change following terrorist attacks. A first general point to make is that changing risk perception can play a role in influencing transportation choice. Evidence from the Prager et al paper in this project suggests that this was the case following the London

2005 bombings, and survey data for both the UK (Goodwin et al, 2005; Rubin et al, 2005, Rubin et al, 2007) and US (Schuster et al, 2001; Schlenger et al, 2002; Lerner et al, 2003) supports this finding. However, this does not appear to have been the case following the attacks in Tokyo.

In this Tokyo case, the role of previous events, specifically the Kobe earthquake two months prior, may have mitigated the social amplification of the terrorist attacks. Equally, the lack of major hazardous events prior to the other terrorist attacks researched in this project may have heightened their shock and impact. The attacks in London, Madrid, and the US were all unprecedented events that appear to have been met with new reactions. Clearly, the relative impact of any attack to previous events is important here.

An important element of the social amplification of risk is that responses to specific hazardous events are likely to be unique across sections of society. This emphasizes the point that culture can play an influential role in transportation mode choice following terrorist attacks both within and between nations and cultures. Indeed, the key debate within the literature on this point is the tension between universalism and cultural relativism, or “cultural theory,” with evidence appearing to support both sides. As risk perception theorists Bernd Rohrmann states:

> “A central idea in Cultural Theory is that people in their risk perceptions express cultural biases which in turn “support” different patterns of social relations. Several attempts have been made to investigate how large a part of risk perception could be explained by cultural aspects, but research on the topic shows diverging results” (Rohrmann, 2000: 178).

For example, Dake (1991) finds evidence to support cultural theory while Sjoberg (1997, 1998) cannot verify this position, and Brenot & Bonnefours (1994) and Goszczynska (1991) both find evidence to support the universal perspective.

In sum, we suggest that the public reaction to terrorist attacks on public transportation systems are influenced by the primary attack characteristics as manifested through the systemic factors and an interactive element of the secondary, socially amplified media, government and public responses, which are clearly also contextual. The purpose here is to explore potential universal variables, as opposed to universal effects per se. It is important to note that not all of these variables are measured within this set of papers.

Implementation Section

These findings have important consequences for policy makers interested the secondary impacts of terrorist attacks. First, our study highlights the potential for reductions in use of attacked transport modes, which have the potential to cause subsequent economic harms and reductions in social welfare. However, these impacts are far from uniform, with divergent results apparently the consequence of distinct primary attack characteristics, social amplification, and transportation system factors.

Second, our findings suggest that supply side factors can influence passenger reductions following the attacks. The London bombing results show that a combination of increased station closures, increased delay times, and reduced service operation all combined to account for around 18 percent of passenger journey reductions for the 4 months following the attacks. This proportion could have been far more substantial had the London Underground not resumed service so quickly, with all lines in operation by August 4, less than a month after the attacks. This highlights the importance of service provision in minimizing the secondary impacts of terrorist attacks.

Third, the results suggest that compounding incidents – in this case the failed attacks of July 21 2005 and the Police killing of an innocent individual – have the potential to increase reductions in passenger journeys. This suggests that policy makers and security officials must balance the potentially conflicting aims of halting multiple attacks while limiting disproportionate security responses. Further research is required to identify the factors which achieve this aim, though such approaches could include increasing non-violent police presence and the incidence of randomized security checks.

Our findings also indicate that policy efforts following terrorist attacks should focus on reducing public risk perception of travel on the affected mode. A key consideration in designing appropriate policy responses is to work towards aligning risk perceptions with risk reality. Risk communication by policy makers after the event has to be crafted in a way that neither unnecessarily alarms nor provides false comfort to people. Actions often speak louder than words. For example, after the London liquid bomb scare of 2006, the US Department of Homeland Security banned all liquids from planes. To some this appeared to be an overreaction, given statistical risk of an attack of this type, but it also did appear to lower public fears and, as a result, had only a minor effect on air travel.

Our findings highlight the opportunity for further research in this area. While it appears that risk perception may play a role in the London bombings case, it is yet to be explored whether the same results have occurred in further terrorist attacks on transportation systems worldwide. Comparison between these cases would enable research to examine the influence that different attack variables – such as the size, type, and location of attacks – may have on risk perception and behavioral responses. It would also be instructive to compare terrorist events with non-terrorist hazards and accidents as this would allow for more general risk perception findings to be revealed, such as the rate at which passengers return to pre-attack mode choices. All such findings have important economic and policy making implications which have also yet to be explored fully.

Future research

Future research could focus on numerous areas. First, improved models and data that enable researchers to control for other variables and estimate the implications for alternative modes. This would be especially support the findings for the Madrid and Tokyo cases. Second, the relationship between risk perception and transportation mode choice can be explored more thoroughly through additional cases such as the February 2004 subway bombing in Moscow, the July-October 1995 metro bombings in Paris, the New York subway following September 11th 2001, and the November 2008 Mumbai attacks. It would also be instructive to compare these findings with non-terrorist hazards and accidents as this would allow for more general risk perception findings to be revealed, such as the rate at which passengers return to pre-attack mode choices. All such findings have important economic and policy making implications which have yet to be explored fully.

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Exploring reductions in London Underground passenger journeys following the July 2005 bombings

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Abstract

We examine the reduction in London Underground passenger journeys in response to the July 2005 bombings. Using entrance data for London Underground stations between 2001 and 2007, we incorporate demand and supply factors in a multivariate time-series regression model to estimate changes in passenger journeys between different Underground lines. We find that passenger journeys fell by an average of 8.3 percent for the 4 months following the attacks. This amounts to an overall reduction of 22.5 million passenger journeys for that period. Passenger journeys returned to predicted levels during September 2005, yet we find evidence of reduced travel until June 2006. Our estimates controlled for other factors, including reduced Underground service provision due to damage from the attacks, economic conditions, and weather, yet substantial reduction in passenger journeys remained. Our analysis suggests that heightened risk perceptions are a significant cause of reduced Underground travel, accounting for around 82 percent of passenger journey reductions following the attacks.

Keywords: Terrorism, Behavioral Responses, Risk Perception, Public Transit, London Underground.

Introduction

Terrorist attacks target human life and civic infrastructure, and aim to inflict economic harm through behavioral changes and business interruption. The immediate effects of terrorism are well documented in the mass media, and the secondary impacts (changes in behavior) are being evaluated with increasing sophistication. One particular area of interest for research has been the behavioral responses to terrorist attacks on transportation systems. Transportation systems are targeted by terrorists because of their potentially high vulnerability, critical position in the economic system, and most importantly, large number of individuals.

Past work has developed around potential transportation modal shifts in response to terrorism events. Looking at the September 11th 2001 attacks, Gordon and colleagues (2007) find substantial reductions in air travel well after the initial attacks and estimate a recovery of the air transit system after 2 years. Ito and Lee (2005) find evidence that shorter distance flights were significantly more impacted than long distance flights, which lends to the substitution hypothesis, where individuals chose to drive instead of fly, while Beeler Asay and Clemens (2009) find evidence that large airports were impacted proportionately more than small airports - the hypothesis being that individuals were more inclined to travel to airports with less perceived risk.

Such transport mode shifts can have disturbing consequences. Gigerenzer (2006) studied changes in highway traffic after September 11th, 2001 and estimated that 1,200 to 1,500 additional individuals died in the United States because they substituted flying for driving (Blalock & Kadiyali, 2005). This behavioral change appears to be in contrast to the objective risk of flying versus driving. Sivak and Flanagan (2003) estimate the fatality risk of driving an average-length nonstop flight (1,157 km) to be 65 times as risky as flying.

Other research has examined the impact of terrorist attacks on ground transportation systems. An unpublished paper by Becker and Rubinstein (2004) studies the changes in bus passenger journeys in Israel following terrorist events. They find that an attack tends to reduce the number of passenger journeys by about 30 percent in the first and second months after an attack. Becker and Rubinstein also find evidence of modal shifts, where individuals choose to ride more taxis after attacks (2004). This stands in contrast to evidence from Spain, where in response to the March 2003 attacks, train passenger journeys reduced yet no substitution towards car travel was observed (López-Rousseau, 2004). Complicating the picture further is unpublished evidence from London which suggests that following the July 2005 bombings, no significant shift in transport mode occurred and there was no subsequent increase in transportation accidents or fatalities (Fasolo et al, 2010). Moreover, evidence from the 1995 Tokyo sarin gas attacks suggests that there was no significant reduction in passenger journeys on the attacked mode (Prager, Fasolo & Ni, 2010). Such contrasting results indicate the necessity for robust analysis of each case rather than generalizations.

The causes of behavioral changes following attacks are less clear. The rational choice model of economic theory suggests that ridership is based on the supply and demand for each transport mode, with individuals maximizing utility so that aggregate transportation behavior moves towards an equilibrium point of optimal social welfare. Economists Becker and Rubinstein (2004) argue that risk and fear should be incorporated into the demand side of this model, especially when considering extreme events such as terrorist attacks. Hence, individual transportation mode choices are influenced by a range of risk and reward factors which include the relative prices, rewards, risks, and fears associated with available transport modes. Two individuals with otherwise identical preferences could choose different modes if their perceptions of the risk were sufficiently distinct.

The role of fear in decision making has been explored extensively in the literature on risk perception (Slovic, 1987), which argues that individual perspectives on uncertain future events are often based upon emotionally driven beliefs – sometimes framed in terms of worry (Sjoberg, 1998) or dread (Slovic, 1987; Fischhoff et al, 1978) – as opposed to calculable risk probabilities. This helps to explain the phenomenon following September 11th 2001, when US airline passengers appeared to switch to statistically riskier road transit (Gigerenzer, 2006). The same story appears in studies on tourism and terrorism, where destinations perceived as riskier are more likely to be avoided (Ichinosawa, 2006; Fischhoff et al, 2004) and willingness to fly is predicted well by the level of worry (Bergstrom & McCaul, 2004).

Changes in risk perception and behavior following terrorist attacks appear to be neither permanent nor homogenous. Burns and Slovic (2007) develop an empirically-derived dynamic model of behavior, in which individuals are shocked into dramatic changes before gradually returning to activities at similar levels to those prior to the attacks. Such dynamism is likely to be exhibited at both the individual and aggregate levels. Changes in risk perception vary across the population and individuals will avoid and return to the attacked mode of transport at differing rates.

We examine the case of the London July 2005 bombings. During rush hour on Thursday, July 7th, 2005, 3 bombings occurred simultaneously on separate London Underground trains, followed an hour later by a bus bombing. These four bombings claimed 822 victims, with 52 dead. These attacks, along with the 4 failed attempts two weeks later, in many ways marked a new era of terrorism on UK soil. They were the first terrorist strikes in the UK of the post-9/11 era. Both attacks were conducted by autonomous cells of Islamic extremists that sought to influence UK government foreign policy by attacking civilians and infrastructure, instilling fear in the general public, and impacting the economy. The use of suicide bombers and targeting of civilians without warning contrasted with the incidents surrounding the Northern Ireland conflict, which until these attacks, was the most recent local terrorism experience for most Londoners. Moreover, while public transportation systems had been targeted previously, the scale and intensity of these attacks on the transport system were unprecedented.

We analyze the aggregate London Underground passenger journey data for 2001-2007, control for supply and demand factors, and still find substantial drops in travel. We find an overall average 7 percent reduction in passenger journeys for the 4 months following the incident, a drop of some 22.5 million passenger journeys; however we find evidence that the reduction could have extended through until June 2006. Our analysis suggests that the July bombings caused individuals to re-evaluate their transportation mode choices. Regression results indicate that external factors such as economic cycles and trends, special events, weather patterns, and transportation prices do not influence the level of passenger journeys greatly during the period in question. Moreover, the most plausible influencing factors – service disruption from station closures and other systemic elements, increased time delays, and lags in passengers returning to the London Underground following full service resumption - do not explain well the sudden reductions following both sets of attacks. Therefore, changes to risk perception are a likely factor in causing model shifts, as suggested by Rubin et al (2005; 2007).

Our study also shows that transportation mode choice changes following such shocks are both dynamic and lasting. These findings raise important questions about the economic impacts and to what extent these are driven by passenger risk perceptions. The findings also suggest, however, that supply side factors – such as service reductions, station closures, and time delays – are significantly influential on London Underground passenger journeys, indicating that policy makers have some level of control over passenger mode choice and potential economic impacts.

Methods

As stated above, numerous studies have made useful contributions to our understanding of transportation mode choice responses to terrorist attacks (Gordon et al, 2007; Ito & Lee, 2005; Beeler Asay & Clemens, 2009; López-Rousseau, 2004; Fasolo et al, 2010; Prager, Fasolo & Ni, 2010). However, this is not to suggest that each is equally valid. The sophistication of methods used to estimate reductions in passenger journeys following the attacks varies substantially. Most use single variable forecasting techniques, whereby counterfactual results are predicted using only historical data for the variable in question. These range from comparisons of year-on-year changes for the given months (Gigerenzer, 2006; López-Rousseau, 2004; Fasolo et al, 2010) to more complex Holt-Winters (Gordon et al, 2007) and ARIMA (Prager, Fasolo & Ni, 2010) forecasting models. As with any single variable analysis, there is the danger that omitted variables may exert influence on the forecasted variable. Though the time-series approaches are able to capture omitted variables with seasonal trends therein, it is clear that single variable forecasting has limitations. Another drawback to some these studies is the aggregation of data to weekly or monthly sets, which neglects the more fine-grained movements of daily data.

We employ multivariate time-series models to estimate the influence of exogenous variables on passenger journeys, and in turn predict changes in passenger numbers resulting from the July attacks.[1] Time series models are generally comprised of both deterministic and probabilistic elements, the latter being referred to as shocks or innovations (Intriligator et al, 1996). In our model, the terrorist attacks are viewed as an exogenous shock to the London transportation system. Deterministic elements include pre-existing trends, cycles, and seasonal components, which are controlled for to avoid inappropriate characterizations of the period. Within this set, both demand side factors, such as economic factors and other special events, and supply side factors, such as station closures, are accounted for. A number of models are estimated, which parameterize the period surrounding the bombings. These models pay attention to the distinct line groupings being impacted, as well specific time periods to account for special events occurring. We estimate the impact of the July bombings by comparing the observed passenger journey numbers with the predicted passenger journey levels. The latter are obtained using the above model without the post July 7th time variables detailed below.

[1] Our model is similar Ito and Lee(2) and Beeler Asay and Clemmens.(3) While these studies produce high explanatory power, with adjusted R^2 greater than 95 percent, it is possible that further influential variables are not accounted for, such as the impact of airline bankruptcies on service supply. Nevertheless, our study incorporates the impact of service supply on passenger journeys.

Regression model and variables

Building upon Ito and Lee (2005) and Beeler Asay & Clemmens (2009) our quantitative analysis takes the following form (variables presented in Table I):

$$
\begin{aligned}
Q_t(\textit{LU travel}) = \beta_0 &+ \alpha_t(\textit{demand factors}) + \partial_t(\textit{supply factors}) \\
&+ \gamma_t(\textit{time factors}) + \varphi_t(\textit{other special events}) \\
&+ \delta_t(\textit{July 2005 attacks factors}) + \varepsilon_t
\end{aligned}
$$

The dependent variable, *LU Travel*, represents the number of passengers entering a London Underground station each day. We observed station data between October 2001 and October 2007. We retrieved from the London Underground Strategic Planning unit in November 2007. The "July 7th indicator" variable examines the impact of the July 7th bombings on the overall dependent variable trend by assigning a "0" to all dates prior to July 7th 2005 and a "1" to that date and beyond. To account for the sudden drop in passenger journeys on the day of the bombings itself, we created an indicator variable of "1" for July 7th 2005 alone, and "0" for all other days.

In line with the Burns and Slovic model described above (2007), we expected the perceived risk of ridership to increase immediately following the event and then slowly fade. As such, passengers would shift away from the attacked transportation mode immediately following the event, before returning gradually to using the London Underground system. In this study we do not examine passenger journey volumes on non-Underground transport modes, and instead treat the group as exogenous to the model. However, to capture this impact, we created an inverse time trend variable for the dates post July 7th. Each day from July 7th 2005 onwards was assigned the value 1/n (e.g. July 7th = 1/1, July 8th = 1/2, July 9th = 1/3, etc, with n referring to the number of days since the attack; Figure 1). We included another indicator variable to capture the impact of the July 21st 2005 attacks, with a "1" assigned to that date and zero to others (Table II).

We created an indicator variable to capture the impact of the "Congestion Charge," a road-pricing scheme aimed to reduce motor vehicle traffic within central London. The introduction of the Congestion Charge in February 2003, allied with substantial investment in public transport, has encouraged many commuters to shift their mode choice away from private motor vehicles. According to Transport for London, car traffic decreased by 30 per cent, with overall traffic reducing by 16 percent (TfL, 2004).

One measurement difficulty in modeling the attacks was the change in congestion charge on July 4, 2005, which increased the price from the initial 5GBP to 8GBP. Thus it was not easy identify the difference in the congestion charge effects and the bombing effects. Nevertheless, we expected that an increase in the congestion charge would increase the traffic on the Underground, implying our estimated results are less in magnitude than what they would have been without the increase in congestion charge.

The 2007 "London Travel Demand Survey" suggests that demand for weekend travel on the London Underground is lower than weekdays (2007). Our data was consistent with that finding, with passenger journeys lower on public holidays. Moreover, the 2007 survey showed that the purpose for weekend use differs from weekday use. Work and education trips dominate during weekday peak hours, yet such journeys are almost non-existent during weekends. Therefore, any weekend and holiday impact revealed by this indicator largely applied to the most common weekend journey types, namely "shopping/personal business" and "leisure" as referred to in the Transport for London (TfL) report. We interacted the weekend and holiday indicator with the July 7 indicator to reveal the impact of the bombings upon passenger journeys during weekends and holidays.

A number of economic and trend factors were included in the regression model. We collected seasonally adjusted data for the monthly Greater London unemployment rate from the UK Office of National Statistics, which uses the definition recommended by the International Labor Organization (ONS, 2005).[2] The population of Greater London has increased since the turn of the century, increasing demand for London public transport. To measure population increase we used UK Office of National Statistics projections for annual mid-year figures (ONS, 2005). We expected the retail price of petroleum to positively influence demand for public transportation. We used monthly retail petrol price data from the UK Department for Business Enterprise and Regulatory Reform (2008). We collected rainfall levels from WeatherOnline, an online meteorological services company (2008). We assume rainfall is more likely to influence the number of London Underground passenger journeys than other weather factors.[3] The rainfall data is from Croydon, a suburb 11 miles from central London and the only meteorological recording station to measure rainfall levels for the majority of days between 2001 and 2007. Dates with omitted data are estimated through a moving average of the previous 30 days.

The period since the turn of the century has witnessed institutional changes, with management of the London Underground network passing from UK central government to the newly formed Greater London Authority. The average price per journey has increased during this period, although the differentiation through various measures such as the Oyster card system means that the distribution of costs is complex.[4] Here, the average revenue generated per passenger journey is calculated through dividing the total revenue earned each year by the number of passenger journeys in that year (TfL, 2008). An unavailable data point for the year 2001 was extrapolated from those retrieved points using linear regression.

[2] We did not collect gross regional product indicators are not incorporated due to lack of data availability. However, we believe unemployment rate measured at the regional level is more instructive than the national economic indicators. Further, intra-urban passenger travel is more associated with employment level than the overall production level.

[3] Both rainfall and temperature are not included because they are correlated, and rainfall is preferred because it is more likely to influence London Underground use.

[4] The lack of specificity here would be of most concern if the price by individuals were correlated with their risk perception.

London Underground stations are periodically closed due to maintenance or other specific reasons, such as the closures following the July bombings. To account for this, a variable is calculated that weighs the days that a station is closed – all the days where less than 100 passing through the gate[5] – by the average passenger entrance numbers for that station between 2001 and 2007. To capture the effects of other service operation, we include two other variables: one that measures the percentage of full service operation for each 4-week period, and a second that provides the average excess journey time passengers faced during each 4-week period. Data for these two variables were from TfL (2010). To adjust for seasonal factors, we used 11 month indicators, in which a "1" is assigned to that month, and a "0" is assigned to all others. In this set of indicators, we omit the month of May, as this is a typical month for passenger journeys.

Our regression models had relatively high explanatory power, with an adjusted R^2 of around 90 percent for all models. The significance of the majority of the variables within the model suggests that the remaining noise is caused by insufficiently fine-grained data or omitted variables. The Durbin-Watson test for auto-correlation was run, providing a result of 1.71. This suggests that auto-correlation may be apparent, causing the possibility of underestimated standard-error terms, inflated t-scores, and hence false positives. To adjust for potential autocorrelation we used Newey-West robust standard errors. Newey-West robust standard errors assume a heteroskadastic error structure, which is possibly auto-correlated with some degree of lag. However, a Dickey-Fuller test on the dependent and independent variables found no evidence of unit-roots. Moreover, we also conducted an inconclusive Johansen co-integration test.[6]

Impact of attacks on London Underground passenger journeys

Following the attacks, London Underground passenger journeys fell sharply (Figure 2). Figure 2 depicts the change in passenger journeys per week, by the dip to the right of both vertical lines, which mark the weeks of July 7th and July 21st respectively. The drop is clearly indicated for all groups of lines, including indirectly affected and unaffected lines (Figure 3).

We estimate that weekly passenger journey volumes were reduced from July through November (Table III). During this period, there was an estimated average 8.3 percent reduction in passenger journeys when compared with predicted levels, though the size of this reduction fluctuated. There was an average 14.1 percent reduction for the two weeks following the July 7 attacks (July 7 – July 20). The reduction rate then increased to an average of 18.3 percent for the two weeks following the second attacks (July 21 – August 3), before gradually receding to around 6 percent in mid-September. Passenger journeys moving briefly above predicted levels in September and November. This

[5] During a station closure, individuals such as maintenance workers will continue to pass through the entrance gates. Analysis of the data shows that this figure did not stray above 100 on days where the passenger numbers were less than 1 percent of average figures.
[6] The Johansen co-integration test did not produce sufficient data to compare the trace statistic or the eigenvalue maximum with the 5 percent critical value. This is possibly due to the presence of multicollinearity.

amounts to a total mean reduction in passenger journeys of 22.5 million for the 4 months following the attacks, with a 95 percent confidence range of 14.9–30.1 million. This is a conservative estimate because the passenger journey reductions appear to have lasted through until June 2006 (Figure 2), by which point there was a cumulative mean estimate reduction of over 38.0 million passenger journeys (Table III).

Explaining the drop in passenger journeys

The one other potential explanation for the drop in passenger journeys is the summer school-break period. This pattern is observable in Figure 2 by the dips during the July and August months of 2003 and 2004. However, Figure 2 also shows that the model incorporates this summer reduction in the prediction for July 2005, and that the observed drop following the attacks is more dramatic than the predicted trend. Moreover, the estimated reductions last through until November, while school age children return early September and university students return in early October.

Yet as time progresses beyond the date of the attack there are a number of competing explanations for the reduction in passenger journeys. In this section we explore these explanations in light of the data, and find that while the supply-side factors such as station closure contributed to the reduction in passenger journeys, there remains a significant portion of the reduction attributable to demand-side factors. Our analysis below suggests that we cannot rule out the hypothesis that the reduction in London Underground passengers was caused in part by altered risk perception in response to the July 2005 bombings.

Service disruption due to station closures

The most compelling alternative explanation for the drop in passenger journeys following the bombings is that station closures for reconstruction caused sufficient inconvenience for individuals that they switched to different transportation modes, or simply did not travel. Indeed, the London Underground system was significantly impacted by the bombings for some time after the event. All stations were closed on July 7th following the attacks. And while the lines not directly affected by the explosions were reopened the following day, directly affected tube lines were reopened in stages, with full service returned by August 4 2005.

There are a number of reasons why the drop in passenger journeys cannot be fully attributed to station closures. First, by breaking the system up into subway lines that were directly disrupted, indirectly disrupted, and undisrupted by the attacks, we have shown that all line groupings experienced reductions in passenger journeys. This is apparent in the Figure 3, as well as the regression model for undisrupted lines in Table IV. However, the networked nature of the London Underground is also an issue. On the one hand, it could be argued that closures to one line would encourage passengers to ride substitute lines, thus offsetting aggregate reductions. For instance, if the specific station could not be reached directly, other transport modes could substitute the final leg of the journey. On the other hand, it is plausible that the lack of a complete London Underground journey could push the individual to choose another transport mode entirely.

Either way, our estimates show that the substantial weekly reductions in passenger journeys remained long after full service was returned to all lines on August 4. We estimate that passenger journeys were reduced by an average of more than 9.2 percent for each week until early September. This could be explained as a lagged effect of the initial station closures; individuals who shifted away from the London Underground may have, for instance, invested in alternative transport modes for a given period, or may have been unaware of service resumption immediately. However, the weight of this explanation is diminished further by the fact that reductions appear to have lasted through until late 2006.

Regression results add further weight to the hypothesis that other factors play a role in London Underground passenger journey reductions following July 7 2005. The variables designed to reflect risk perception elements – the "July 7 indicator" and "Inverse days since July 7" – are both significant. This is despite the statistical significance of the supply-side station closure, service reduction and time delay variables, which all changed in the expected manner following the July 2005 bombings; the number of station closures increased, the proportion of total kilometers operated was reduced, and time delays increased.

We estimate that the contraction of London Underground service following the attacks caused a 4.1 million reduction in passenger journeys. This accounted for 34 percent of total passenger journey reductions during the first month following the attack. However, this proportion diminished to 5.5 percent for the second month, and no amount thereon. This suggests that demand side forces account for around 18.4 million (82 percent) of passenger journey reductions in the 4 month period following the attack.

Demand Side Factors

The reasoning in the three previous paragraphs suggests that supply side factors cannot alone explain the reduction in passenger journeys. Yet it is not clear what demand side factors can also explain the reduction. The impact of the July 21 bombings provides some clues to this effect. Despite no additional station closures and no further deaths or injuries, passenger journeys dropped in the weeks following the July 21 attacks. It appears that the compounding impact of a second attack, combined with the Police killing of the innocent Brazilian citizen Jean Charles de Menezes on July 22, caused individuals to shift away from the London Underground. Despite the importance of such a question for policy makers, it is impossible to tell from this data which incident had more effect on transportation mode choice. In any case, it stands to reason that individuals would have altered their risk perceptions of travel of the London Underground as a result of either of the incidents.

We do not have the survey data necessary to validate such an explanation, which would require the same random sample of respondents to be interviewed before and after the attacks. Nonetheless, three surveys surrounding the July bombings (Rubin et al, 2005; 2007; Goodwin et al, 2005) collectively suggest that the fear of traveling caused British individuals to travel less. One study suggests changing risk perceptions of terrorist events was sufficient to cause a small minority to avoid traveling into central London prior to the July 2005 bombings (Goodwin et al, 2005). More importantly, some 30 percent of respondents 11-13 days after the July 7th bombings declared that they planned to travel less often as a result of the attacks (Rubin et al, 2005). In the follow up survey also conducted by Rubin et al (2007), only 19 percent reported traveling less during 2006 in response to the bombings. These figures are a similar magnitude to our aggregate results.

One possible drawback here is the omission of tourists. However, international tourists represent only a small proportion of individuals in London at any one time – less than 5 percent on average – and they are significantly less likely to use public transportation than London or UK residents (ONS, 2010). Though these surveys did not all ask questions regarding travel into central London via the London Underground, the results suggest that such risk perception explanations cannot be rejected. The use of aggregate data is another limitation as it restricts deeper exploration of transportation mode choice following terrorism events. This data does not reveal individual level decisions, preferences, or risk perceptions.

However, thanks to the different ridership patterns on weekend and weekdays we are able to assess the influence of trip purpose on post-incident ridership. In another finding to support the influence of risk perception hypothesis, weekend passenger journeys took a much longer time to return to predicted levels than the weekday passenger journeys. This is shown by the significance of the "weekend and holiday X July 7th" interaction variable in the regressions results presented in Table V. It stands to reason that less essential weekend journeys are impacted to a greater magnitude and for longer if individuals are influenced by the shift in risk perception following the attacks. This finding highlights the importance of both risks and rewards for transportation mode choice; where rewards are diminished, risks play a more prominent role. However, survey data to validate this hypothesis is unavailable. These particular results have important consequences economically, suggesting that sectors which rely on the non-commuter travel more prevalent at weekends – such as central London retail and entertainment industries – were disproportionately impacted (TfL, 2008).

Beyond the issues of station closures and risk perception, other factors such as economic cycles, seasonal components or trends are important to consider. As shown in Table V, most other model variables are significant in the regression results. Yet the data for some of these variables are monthly, which stands in contrast to the daily data for the dependent variable and may create noise within the regression estimations. Special events are also considered. Numerous popular events occurred during the time period observe; however, we assume that such events are regular enough to be a treated as white noise. Nonetheless, this could be a source of noise within the model that is not currently accounted for. The introduction and increased fairs of the Congestion Charge are other special events within the model, which we would expect to increase the number of Underground passenger journeys as individuals on the margin shift away from private road vehicles included in the scheme. Interestingly the Congestion Charge variable carries a negative coefficient in our regression results, which may be the result of the concomitant improvement in bus service, though may also be the result of collinearity among similar variables.[7]

Conclusions

We estimated the magnitude and length of passenger journey reductions from the London Underground bombings in July 2005. Both supply and demand-side factors are then explored in a multivariate time series regression model as explanations for the reductions. While passenger journey reductions can be attributable to station closures in part, demand side factors such as economic and trend variables, also appear to contribute to the reductions. Yet a substantial reduction in passenger journeys remains unexplained. These findings, when combined with psychological surveys conducted around the event (Rubin et al, 2005; 2007; Goodwin et al, 2005), suggest that altered risk perceptions influenced individual transportation mode choice during this period.

The reduction in London Underground passenger journeys following the July 2005 bombings can be explained in part by passengers' heightened risk perceptions regarding further attacks. We find an estimated at 22.5 million fewer journeys (8.3 percent) for the 4 months following the attacks, though reductions appear to have lasted into 2006. Our analysis suggests that heightened risk perception is the major demand side influence on reduce passenger journeys, accounting for around 18.4 million (82 percent) of passenger journey reductions in the 4-month period following the attack.

These findings appear to be similar to that experienced on domestic airlines following the September 11th 2001 attacks – around 8 percent for the first year and 4 percent for the second (Gordon et al, 2007). And the reduction is more than the 4-6 percent observed for the 2 months following the 2003 Madrid attacks (López-Rousseau, 2004) and the lack of impact following the 1995 Tokyo sarin gas attacks (Prager, Fasolo & Ni, 2010). This phenomenon, whereby heightened risk perception following a terrorist attack leads individuals to shift away from the impacted transport mode, has also been observed in the aftermath of other recent terrorism events.

This is not to say that these risk perceptions are only based on fear and not on fact. Clearly, the terrorist event itself is a signal that reasonable people should take into account when assessing the risks of a future attack. It is likely though, that for a period of time, the risk perceptions are heightened relative to the actual risks of transportation, thus leading to a temporary overreaction to the terrorist attack. The fact that the sarin attack in Tokyo had no or little impact on travel behavior suggests that heightened risk perceptions are created primarily by very large and dramatic events.

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[7] The VIF test does not show the Congestion Charge variable to exhibit multi-collinearity, though other variables do fail the test.

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Table I: Variables included in the regression model and expected coefficient signs

Variable	Description	Expected Coefficient Sign
Passengers in	Daily passengers entering London Underground station gates	
Time	Continuous daily series, Jan 1 2001 to Oct 8 2007	Positive: service improved during period.
July 7^{th} indicator	"1" for dates July 7^{th} 2005 and after, "0" for all others	Negative: significant reduction expected for period following attacks.
July 7^{th} only indicator	"1" for July 7^{th} 2005, "0" for all others	Negative: significant reduction expected on day of attacks.
Inverse days since July 7^{th}	Inverted continuous series beginning July 7^{th} 2005	Negative: significant reduction expected through this period.
Congestion charge indicator	"1" for dates Feb 17 2003 and after, "0" for all others	Positive: As road use increases, London Underground likely to increase.
Weekend and holiday indicator	"1" for weekend and holidays, "0" for all others	Negative: London Underground less busy on weekends and holidays.
Weekend and holiday X July 7^{th}	Interaction between "Weekend and holiday" and "July 7^{th}" indicator variables	Negative: London Underground likely less busy on weekends and holidays following attacks.
Unemployment rate	Monthly unemployment rate of Greater London area	Negative: decreases demand.
Population	Annual population of Greater London area	Positive: increases demand.
Petrol price	Monthly average UK retail petrol price	Positive: increases demand.
Revenue per passenger	Average price of London Underground passenger journeys	Negative: decreases demand.
Proportion of service operation	London Underground train kilometers operated as a percentage of full service capacity	Positive: reduces congestion which increases demand.
Excess journey time	Average excess journey time on the London Underground resulting from delays	Negative: increases travel time, which reduces demand.
Weighted station closure	Dates station closed weighted by average passenger entrances for that station	Negative: increases barriers to entry.
Rainfall	Inches of rainfall recorded at Croydon, a suburb of London	Positive: reduces substitution modes such as bus, motor-bicycle and bicycle.

Month indicators	Set of indicator variables, one for each month, May excluded	Positive in winter, negative in summer.

Table II: Time Variables Equations

$$Q_t = \beta_0 + \alpha_t + \partial_t + \gamma_t + \varphi_t + \delta_t + \varepsilon_t$$

$$\delta_t = \begin{cases} 0 \text{ if } t < t_F \\ \delta_1 + \delta_2 + \delta_4 \text{ if } t = t_F \\ \delta_2 + \delta_4(t - t_F)^{-1} \text{ if } t_F < t < t_S \\ \delta_2 + \delta_3 + \delta_4(t - t_F)^{-1} \text{ if } t = t_S \\ \delta_2 + \delta_4(t - t_F)^{-1} \text{ if } t > t_S \end{cases}$$

Where:

Q_t = Passengers entering London Underground stations

β_0 = Intercept term

α_t = Demand factors

∂_t = Supply factors

γ_t = Time factors

δ_t = Coefficients on regression variables:

- δ_1 = July 7 only indicator
- δ_2 = July 7 indicator
- δ_3 = July 21 indicator
- δ_4 = inverse days since July 7

ε_t = Error term

t = Time in days

t_F = July 7

t_S = July 21

Table III: Monthly change in London Underground passenger journeys (2005-2006)

Four-week period commencing	Mean Estimate	Upper Bound	Lower Bound
7-Jul-05	11.2m	9.4m	13.0m
4-Aug-05	7.3m	5.7m	8.9m
1-Sep-05	3.9m	2.4m	5.3m
29-Sep-05	-0.6m	-2.2m	0.9m
27-Oct-05	0.8m	-0.5m	2.1m
24-Nov-05	-2.5m	-4.2m	-0.8m
22-Dec-05	7.7m	5.4m	10.1m
20-Jan-06	1.1m	-0.3m	2.5m
17-Feb-06	2.7m	1.5m	3.8m
17-Mar-06	2.2m	1.1m	3.3m
14-Apr-06	2.8m	1.6m	4.0m
12-May-06	1.5m	0.3m	2.7m
9-Jun-06	1.0m	-0.1m	2.2m
7-Jul-06	0.8m	-0.6m	2.2m
4-Aug-06	-0.4m	-1.7m	0.9m
1-Sep-06	1.8m	0.4m	3.1m
8-Sep-06	0.8m	-0.8m	2.3m
20-week impact 7-Jul-05 to 23-Nov-05	22.5m	14.9m	30.1m
48-week impact 7-Jul-05 to 8-Jun-06	38.0m	20.3m	55.8m

Table IV: Regressions of daily London Underground passenger journeys (2001-2007)

Thousands of Passengers	All Lines	Unaffected Lines	Pre July 7 2005
Time	0.18	0.106	1.05***
	(0.78)	(1.17)	(3.25)
July 7 2005 indicator	-85.95**	-44.24***	
	(-2.05)	(-2.66)	
Congestion Charge indicator	-187.30***	-59.50***	-69.29
	(-4.71)	(-3.82)	(-1.62)
July 7 2005 only indicator	-112.00	-128.8	
	(-0.28)	(-0.83)	
Inverse days since July 7 2005	-2,041.9***	-734.5***	
	(-4.78)	(-4.50)	
July 21 only indicator	-384.9***	-142.4***	
	(-9.50)	(-8.90)	
Weekend and holiday indicator	-1,129.4***	-482.2***	-1,122.6***
	(-54.62)	(-45.17)	(-49.09)
Weekend, holiday X July 7 2005	-143.00***	-34.76***	
	(-5.92)	(-3.77)	
Monthly unemployment rate	-13.56	-0.109	47.35
	(-0.68)	(-0.01)	(1.05)
Annual population	0.002***	0.00149***	0.005***
	(2.59)	(4.13)	(4.14)
Monthly petrol price	-1.57	0.794	12.93**
	(-0.64)	(0.82)	(2.00)
Revenue per passenger	-92.98	-1062.5	-9,873.60***
	(-0.05)	(-1.39)	(-3.50)
Weighted station closure	-1.07***	-1.047***	-1.13***
	(-9.41)	(-9.04)	(-7.79)
Proportion of service operation	14.42***	5.864***	-1.31
	(3.04)	(3.12)	(-0.25)
Excess journey time	30.32***	14.18***	-3.03
	(3.89)	(4.58)	(-0.32)
Rainfall	-4.28***	-1.642***	-5.97***
	(-3.14)	(-3.02)	(-3.43)
January indicator†	-175.00***	-51.19***	41.16
	(-4.82)	(-3.64)	(0.77)
Intercept	-15.68	-10,810.3***	-34,986.6***
	(-0.54)	(-4.24)	(-4.20)
N	2,159	2,159	1,335
adj. R-sq	0.887	0.894	0.879

t statistics in parentheses

* p<0.10, ** p<0.05, *** p<0.01, † Other months hidden

Table V: Summary statistics for regression analyses (2159 observations, indicator variables not presented)

Variable	Mean	Standard Deviation	Minimum	Maximum
Passengers ('000s)				
All lines	2,425.9	725.2	0	3630.7
Directly affected lines	1,019.9	302.0	0	1499.1
Indirectly affected lines	961.3	301.1	0	1410.4
Unaffected lines	848.3	259.1	0	1316.9
Pre-July 7 2005	2,303.6	681.1	0	3197.7
Unemployment Rate (%)	7.1	0.4	6.2	8.1
Petrol Price (GB Pence)	82.7	8.1	69.9	97.6
London Population ('000s)	7,432.8	74.1	7,322.4	7,558.4
Revenue Per Passenger (GB Pounds)	1.4	0.1	1.3	1.6
Rainfall Daily (cm)	2.1	4.5	0	49.0
Kilometers Operated (% of total)	93.6	3.0	80.2	96.5
Excess Journey Time (minutes)	7.7	1.6	6.3	16.8

Figure 1: London Underground passenger journeys, all lines, observed and predicted (2003-2006)

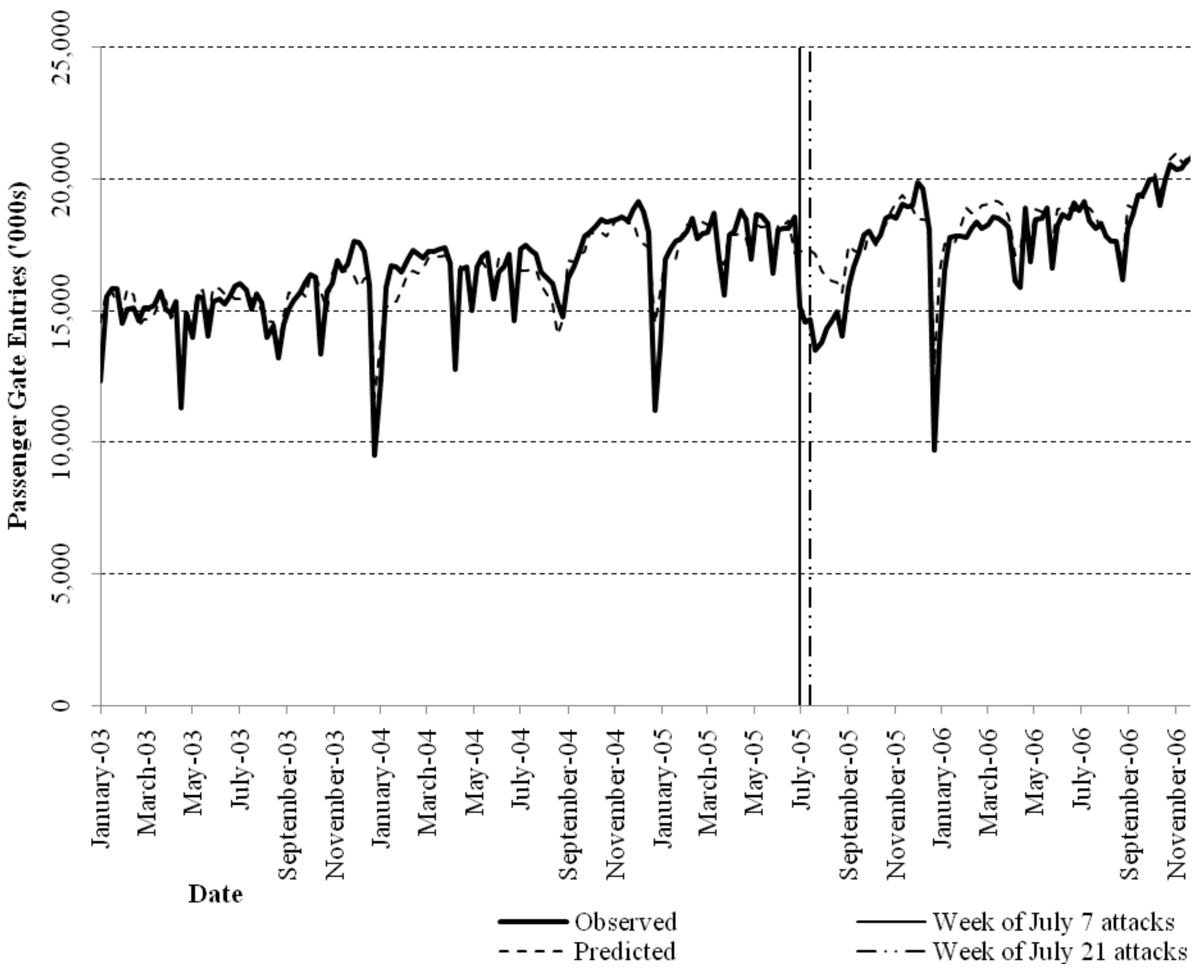


Figure 2: London Underground passenger journeys, all lines, observed and prediction 95-percent confidence intervals (2003-2006)

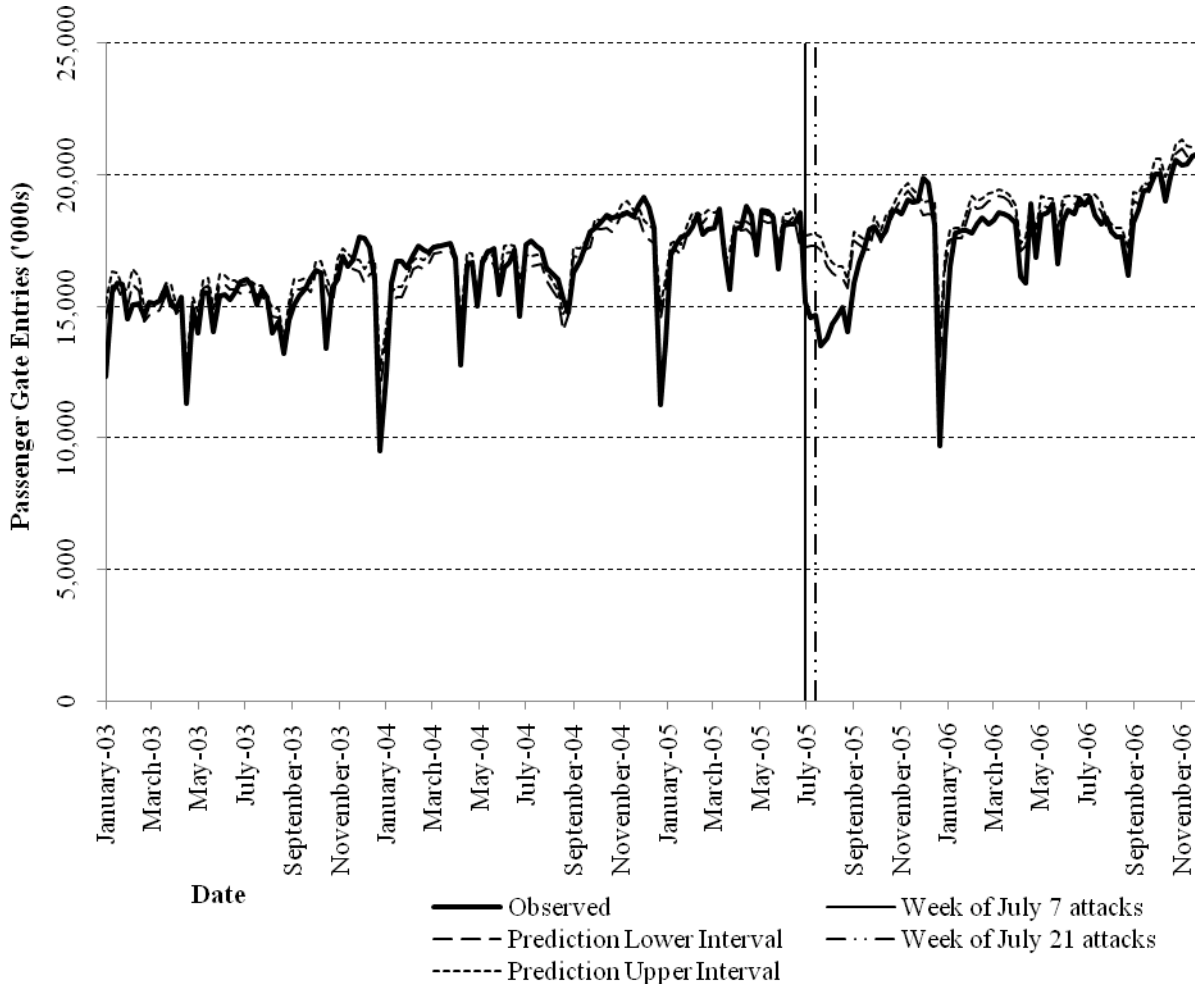
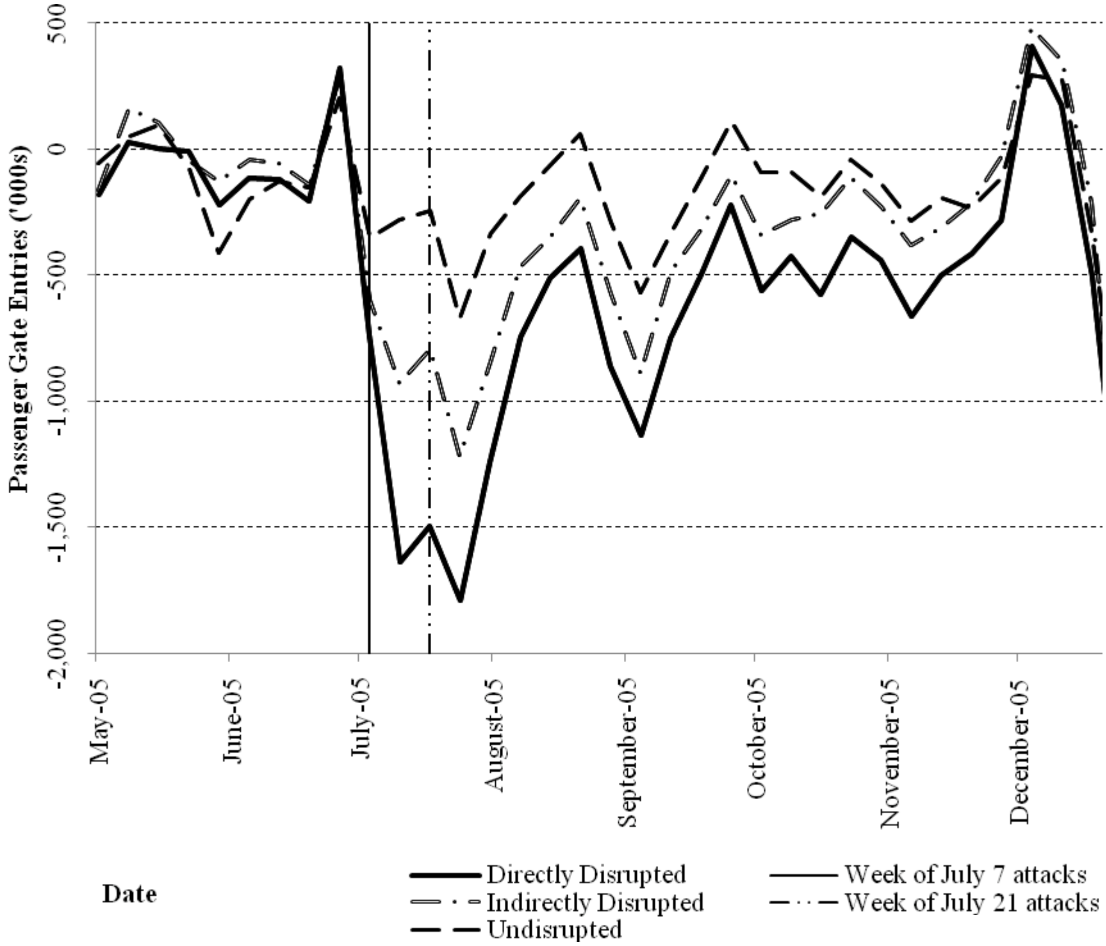


Figure 3: Change in London Underground aggregate weekly gate entrances by line grouping (2005)



A study of the impact of the July bombings on Londoners' travel behavior

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Introduction

On the 7th of July 2005, at the peak of morning rush hour, three bombs exploded in short intervals on three London Underground trains. Nearly an hour later, a fourth bomb exploded on a double-deck bus. The bombings killed 52 commuters and the four suicide bombers, injuring over 700[8]. This paper presents an analysis of the impact of these bombings (7/7) on Londoners' use of transportation in the aftermath of 7/7 and the risk perception that this use reveals. Analysis of behavioural reactions to 9/11 (the terrorist attack on US commercial passenger airlines on 11th of September 2001) suggests that terrorists 'strike twice' – first claiming lives and damaging infrastructure directly, during the course of the attack, and then indirectly, through people's heightened perception of the risk of a repeated attack on the mode directly attacked, causing a shift to a riskier transport mode (Gigerenzer, 2006). However, Spaniards' reactions to the Madrid train bombings on 11th of March 2004 (M/11) did not show evidence of such second indirect damage (López -Rousseau, 2005). This paper examines whether Londoners' experience was closer to the US or Madrid, and finds that although London's terrorist attack met the conditions for unleashing similar reactions to M/11, Londoners' experience of 7/7 was different from both US citizens reactions to 9/11 and Spaniards' reactions to M/11. We examine four different explanations for the disparity and offer a policy implication, to be substantiated by further analysis.

Behavioral reactions to 9/11 and M/11

The impact of terrorist attacks on travelers' behavior has been analyzed both in the aftermath of 9/11 (Gigerenzer, 2004, 2006), and in the aftermath of M/11 (López-Rousseau, 2005). These analyses revealed that the attacks had a powerful effect on travellers. For instance, Gigerenzer (2006) found that for a period of one year after 9/11, air travel dropped below the five-year average preceding the event and was substituted by car travel. Since travelling by car kills more than traveling by air (Slivak and Flannagan, 2003), he hypothesized, and found, that such substitution claimed lives: Highway fatalities increased as a result of drivers avoiding airplanes, the *dread risk* (defined as a low-probability and high damage event).

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[8] The terrorists struck twice in London in the same month. The second attack occurred exactly two weeks later on July 21st: three bombings were attempted on the London Underground, and one on a bus. None of the main explosive charges detonated, and there were no casualties. It is possible that both attacks influenced people's behavior. Due to the short interval between the two attacks, it is impossible to single out their individual effects. So the subsequent analysis can be viewed as examining their joint impact, with 7/7, the attack that had incurred direct life losses being the leading factor underlying Londoners' subsequent behavioral changes.

Gigerenzer's 'dread hypothesis' rests on three interlinked conditions, and an implicit fourth:

> 1) dread avoidance, evidenced by a decrease in the use of the transportation mode directly attacked by the terrorists and therefore 'dreaded';
> 2) substitution, evidenced by an increase in the use of the modes that serve as the substitute of the mode attacked and dreaded; and 3) increase in fatality. For 3) to take place, an important implicit condition is that 4) the substitution mode is riskier, that is, associated with higher fatality rates than the attacked mode.

This was the case in the US, where after 9/11 car travels increased especially on the rural interstate highways. Interstate highways are the more likely candidates for substituting within-US air travels; they are also associated with a higher fatality rate than air travel. Indeed, Gigerenzer found that more people died on the roads following 9/11. Immediately following the attack, the number of fatal crashes rose above the five-year maximum (1996-2000) for each month and remained so for a period of six months; this number only returned to the five-year average one year after 9/11. Gigerenzer considers this the 'indirect' damage caused by terrorists. Terrorists strike twice, first physically on people and infrastructure, then psychologically, through people's minds.

Interestingly, analysis of Spaniards' travel reactions to the Madrid terrorist attack yields different results from the US. Specifically, López-Rousseau found dread avoidance (rail usage fell following M/11), but no dread-induced substitution (no increase in car patronage). Consequently, he found no increase in fatality (measured by *interannual variations*, or the percentage difference between a measure in a given period and the same period a year earlier, also called *year-on-year changes*).

López-Rousseau (also see Gigerenzer, 2006) proposed three explanations for the apparent disparities between the US and Spain and for the lack of substitution in particular. First, Spain has a history of terrorist attacks which the US has not. Past exposure to a risk increases people's knowledge of the risk, and thereby decreases its perceived 'riskiness' (Slovic, 1987). Second, Spain is less of a 'car culture' than the States. Third, Spain has more developed public transportation systems. These two suggest that compared to Americans, Spaniards are less likely to replace the affected public transportation mode (train travel) as well as less likely to substitute it with car.

On these three accounts, we consider Britain to be more similar to Spain than to the US, leading us to expect that Londoners' reactions to 7/7 should also show no evidence for indirect damage in terms of increased fatality, as well as no evidence of substitution. First of all, the UK has for decades had to deal with terrorist events. For instance, in 1993, the Provisional Irish Republican Army (IRA) detonated a truck bomb in London's financial district in the City of London, killing one person and injuring 44. In terms of the efficiency of public transportation systems, London has well-developed underground and bus networks. The car culture is perhaps most distinctive in the States. Americans have the highest number of vehicles per capita, almost twice as many as British or Spaniards[9]. Besides the attitude, the incentive to

[9] http://en.wikipedia.org/wiki/Image:World_vehicles_per_capita.svg. Last accessed: 03 July, 2008

substitute public with private transportation (car) might even be lower in London than Madrid, due to the congestion charge introduced in February 2003. This is a daily charge of £8 ($16) for anyone who drives into the congestion charge zone, which covers most of central London. A last important aspect that makes 7/7 similar to M/11 is the fact that both were attacks on ground transit – unlike 9/11.

Methodology

We collected five-year transportation data, from 2002 to 2006, from the transportation authorities of the UK and London, i.e. *Department of Transport* and *Transport for London*. These include: yearly traffic volume of buses[10], cars[11] and taxis (as one mode), pedal cycles and powered-2-wheelers[12], weekly traffic volume of London underground (in charts), and fine-grained fatality and casualty data by London borough, by transportation mode, and by month. We analyzed the data by measuring interannual variations. For fatalities and casualties, we also compared the data to the average, maximum and minimum of each month of three years before 2005 (from 2002 to 2004). We measured the 'riskiness' of each transportation mode by *fatality rate* in persons killed per million vehicle kilometres, or the number of fatal injuries divided by traffic volume of each transportation mode. This measurement allows us to tease out the usage of a mode as a contributing factor of the changes in the fatality. To examine whether the changes in fatality in 2005 were due to 7/7, we computed 6-month fatality ratios, by using the total fatalities in the second-half of 2005 (from July to Dec) divided by those in the first half (from Jan to June), and again compared this ratio in 2005 to those in the previous three years (from 2002 to 2004).

Results

The following section presents our results in the logical order suggested by Gigerenzer's 'dread-hypothesis': 1) Did avoidance occur? 2) Did substitution occur? And 3) Did fatalities increase?

1) Did avoidance occur?

The modes of transportation directly affected by the terrorists were the London underground (also called the 'tube') and buses. Avoidance would therefore occur if we found that passenger volumes decreased on both the tube and buses immediately following the attack of 7/7 (and possibly after the failed attack of 21/7), and gradually returned to the pre-7/7 baseline.

The tube weekly passenger entry data collected from *Transport for London* (Table 1) showed a 12.8% drop in the week immediately following 7/7 during weekdays; the impact on weekends was even larger – a 32% decrease occurred.

[10] Buses include buses and coaches.
[11] Cars do not include goods vehicles.
[12] Powered-2-wheelers include motor cycles and mopeds.

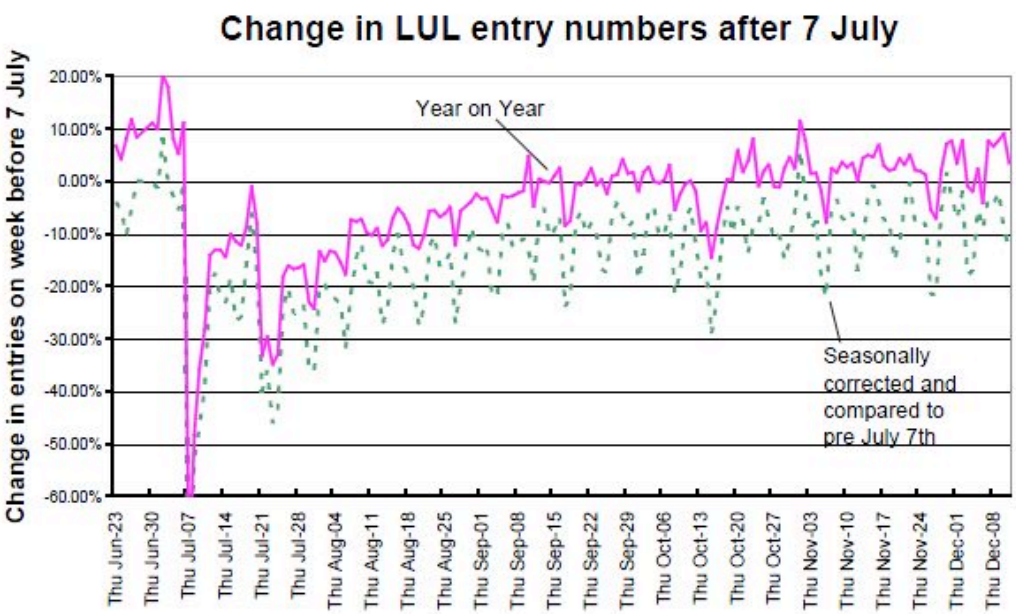
Table 1: Interannual variations of London Underground entry: 2005 versus 2004.

	Week commencing					
	16-Jul	23-Jul	30-Jul	06-Aug	13-Aug	20-Aug
Weekday entries	-12.8%	-15.9%	-16.5%	-14.0%	-8.6%	-5.6%
Weekend entries	-32.7%	-11.6%	-34.0%	-23.4%	-13.5%	-11.7%
Weekly total entries	-16.5%	-15.1%	-19.7%	-15.7%	-9.5%	-8.4%

Source: Transport for London

As shown in Fig.1, the decrease probably lasted for at least two months till mid-September (the solid line). But since underground patronage had been increasing robustly since the beginning of 2005 (the lines were well above the 0% base-line, which indicates the monthly average of the previous three years), seasonally-corrected data revealed that the effect might have lasted till early December (the dashed line). While these results do not allow us to distinguish between avoidance on directly hit lines (which were closed in certain sections until early August) and avoidance on lines not hit, research that has examined this difference found that avoidance occurred also on lines not hit (Prager, Beeler Asay & von Winterfeldt, 2009).

Figure 1: Weekly tube usages in 2005 compared to 2004.

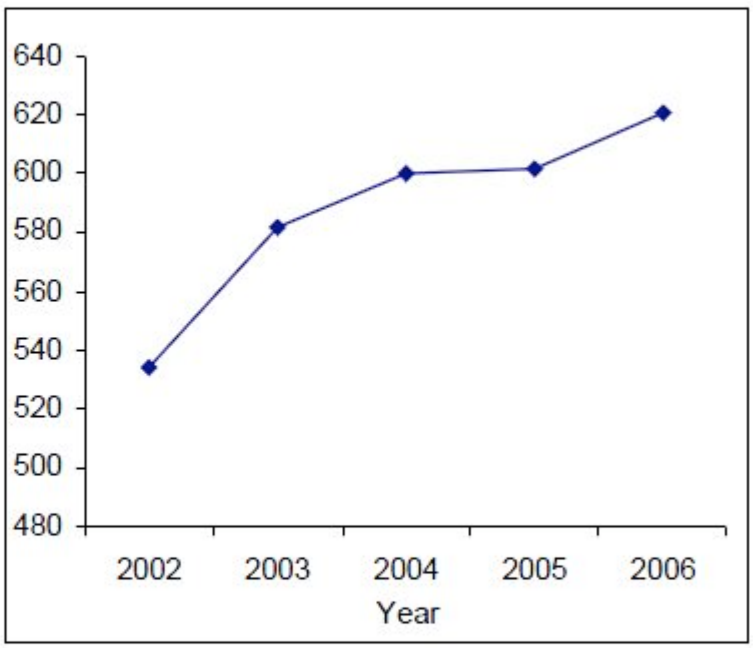


The baseline (0%) is the weekly entry of 2004 in the same week. The solid (red) line shows the actual weekly entries in 2005 compared to 2004; the dashed (green) line show the seasonally-corrected weekly entries. The sudden drop corresponded to the week of 7/7. Although the actual weekly entries suggest that the tube usages recovered in mid-September, the seasonally-corrected data show that the recovery did not occur till early December. Source: Transport for London.

As for buses, avoidance is less obvious (Figure 2), mainly because the data currently available is aggregated yearly. The traffic volume of bus and coach in 2005 was comparable to that in 2004. Nevertheless, the year on year % change reveal that before 2005, bus use had been increasing robustly for two years in a row, but stopped in 2005 (0.33%), and again resumed in 2006 at the 2004 rate. Thus, it is possible that bus use was affected. To better address this question, we will continue to seek monthly bus traffic volume data for 2005.

Figure 2: Yearly traffic volume of bus or coach in London.

Million vehicle kilometers	2002	2003	2004	2005	2006
Bus or Coach	534	582	600	602	621
Year on year change (%)		8.99%	3.09%	0.33%	3.16%



The trend lines show that the bus usage in 2005 was comparable to 2004.
Source: Department of Transportation

2) Did substitution occur?

The dread hypothesis posits that travelers avoid the transportation mode directly hit by the terrorists (underground and bus) by substituting it with viable substitutes. Among the possible transportation modes, e.g. pedestrian, pedal cycle, powered-2-wheeler, car and taxi (as one mode), airline, and boat, we considered pedal cycle, powered-2-wheeler, and car and taxi as the most likely substitutes for underground and bus. Table 2 and Fig.3 show the yearly transportation volume by transportation mode in London between 2002 and 2006, as well as the interannual variations of each mode.

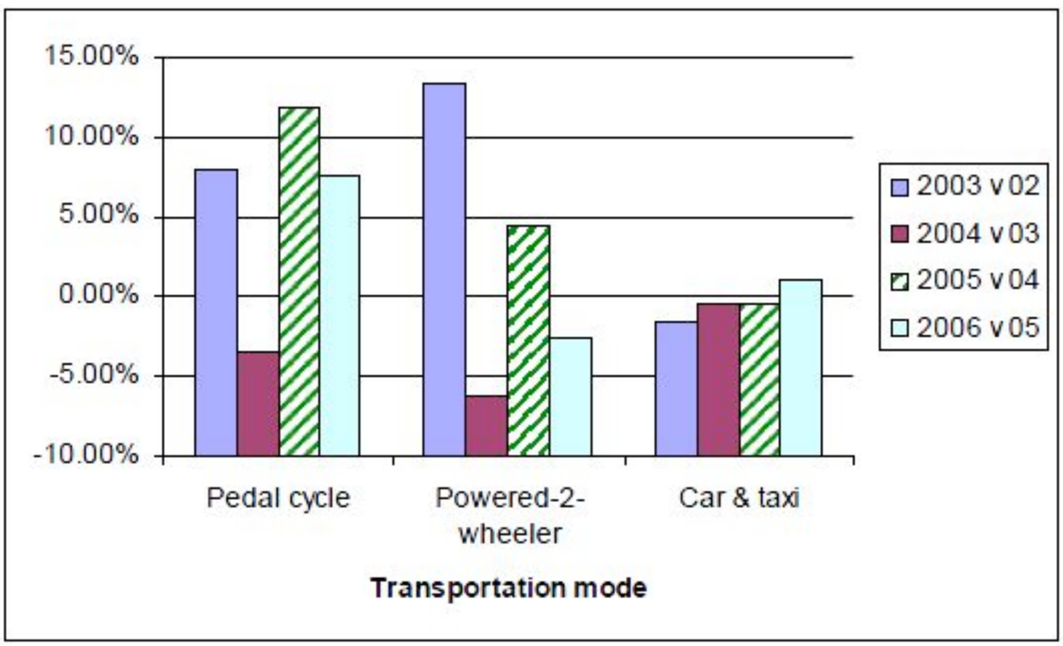
The year-on-year changes between 2005 and 2004 (the green shaded bars) reveal an increase in the use of pedal cycles and powered-2-wheelers, but a slight decrease in that of cars and taxis. These data suggest that pedal cycle and two-wheeled motor vehicles, and in particular the former, probably served as the substitutes for the tube and buses.

Table 3: Yearly London traffic volume (in million vehicle kilometres) **and *interannual variations*** (as %).

	2002	2003	2004	2005	2006
Pedal cycles	502	542	523	585	630
		7.97%	*-3.51%*	*11.85%*	*7.69%*
2-wheeled motor vehicles	762	864	809	845	823
		13.39%	*-6.37%*	*4.45%*	*-2.60%*
Car & Taxi	26,795	26,376	26,269	26,136	26,398
		-1.56%	*-0.41%*	*-0.51%*	*1.00%*

Source: Department of Transportation

Figure 3: Interannual variations of London traffic volume by mode.



Shaded bars show the change percentages of 2005 compared to 2004 (shaded bars), which suggest an increase in pedal cycles and 2-wheeled motor vehicles (powered-2-wheelers), but a decrease in cars and taxis.

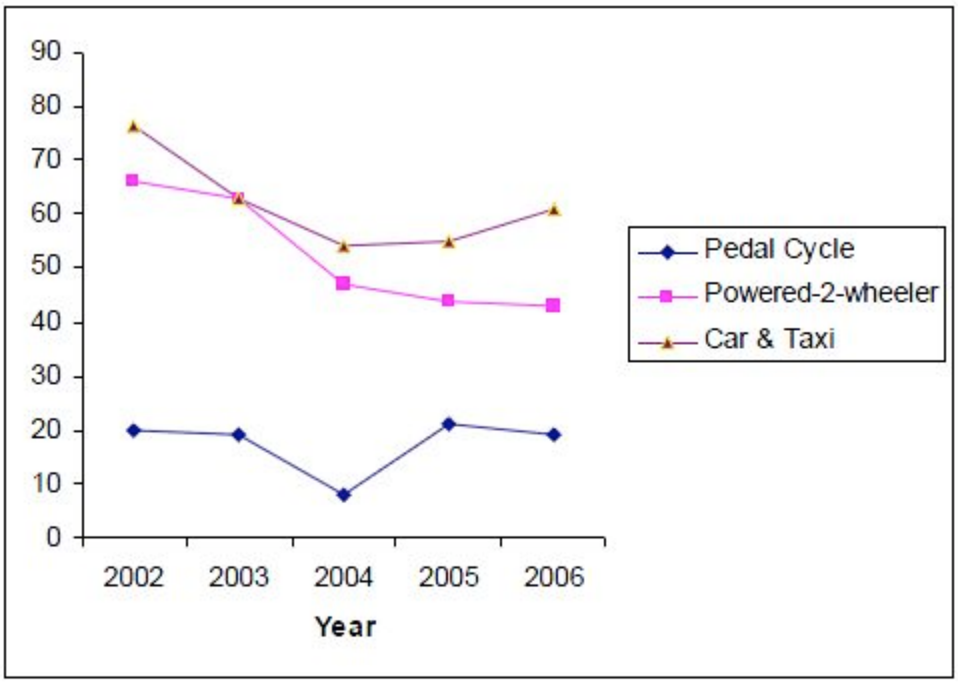
3) Did fatalities increase?

The last condition of the dread hypothesis requires that fatalities increased as a result of avoidance and substitution. We examine evidence for this condition by first comparing the yearly fatalities (number of deaths) caused by the three modes reputed to be substitutes to the tube and buses. Note that we also included 2006 data, as this would allow us to examine whether an increase in 2005 fatality was unique or simply reflected a general trend towards long term increase.

Table 4: Annual fatalities by transport mode

	2002	2003	2004	2005	2006
Pedal Cycle	20	19	8	21	19
Powered 2-wheeler	66	63	47	44	43
Car & Taxi	76	63	54	55	61

Figure 4: Annual fatalities by transport mode.



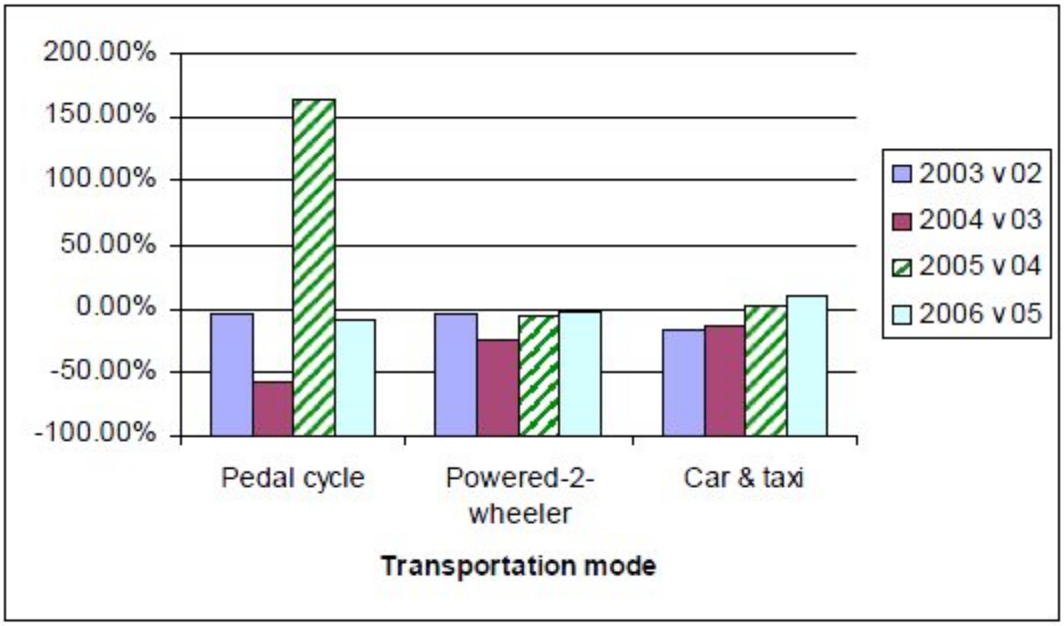
These trend lines show that the fatality of pedal cycle was the highest in 2005 compared to both the years before and the year after, a distinctive pattern not shared by the other two modes, i.e. powered-2-wheeler and car and taxi.

Fig. 4 shows that the fatality of pedal cycle increased in 2005 compared to 2004, but that of powered-2-wheeler decreased. This point is perhaps better illustrated in the interannual variations in fatality (Fig.5). It is clear from Fig.5 that the only salient increase in fatalities in 2005 happens to pedal cycle. Since as discussed, pedal cycle is a substitute mode for avoiding the dread of underground and buses, this increase could provide support for Gigerenzer's dread hypothesis if we find evidence that this increase is due to the July bombings. That is, the increase in fatalities should occur in the second-half of 2005, from July to December, rather than in the first half, from January to June. To investigate this, we first collected monthly fatality data for the three transportation modes, plotted below. This is then followed by the half-monthly data analyses.

Table 5: Interannual variations of fatality in London by mode

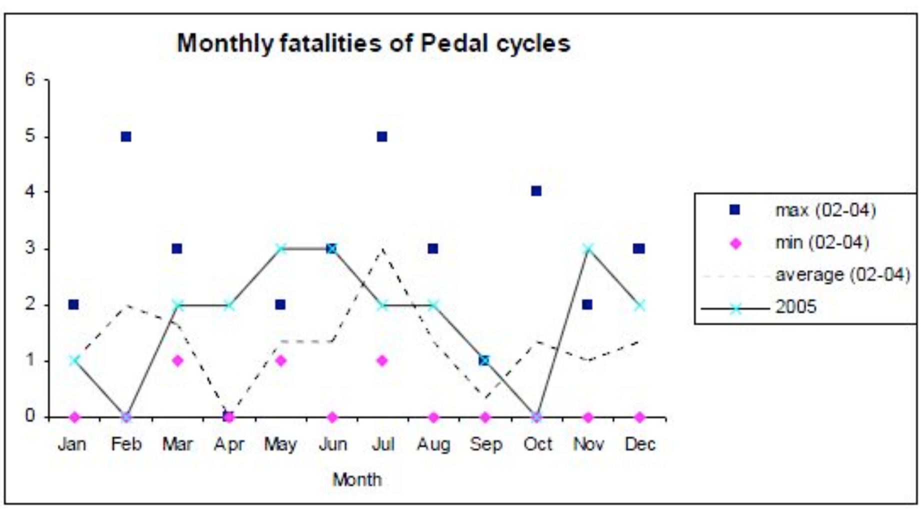
	2003 v 02	2004 v 03	2005 v 04	2006 v 05
Pedal cycles	-5.00%	-57.89%	162.50%	-9.52%
2-wheeled motor vehicles	-4.55%	-25.40%	-6.38%	-2.27%
Cars & taxis	-17.11%	-14.29%	1.85%	10.91%

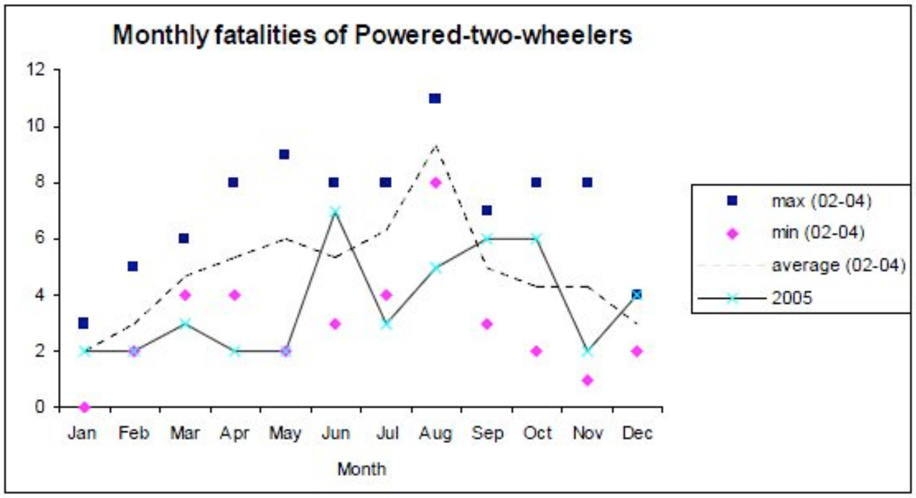
Figure 5: Interannual variations of fatality in London by mode

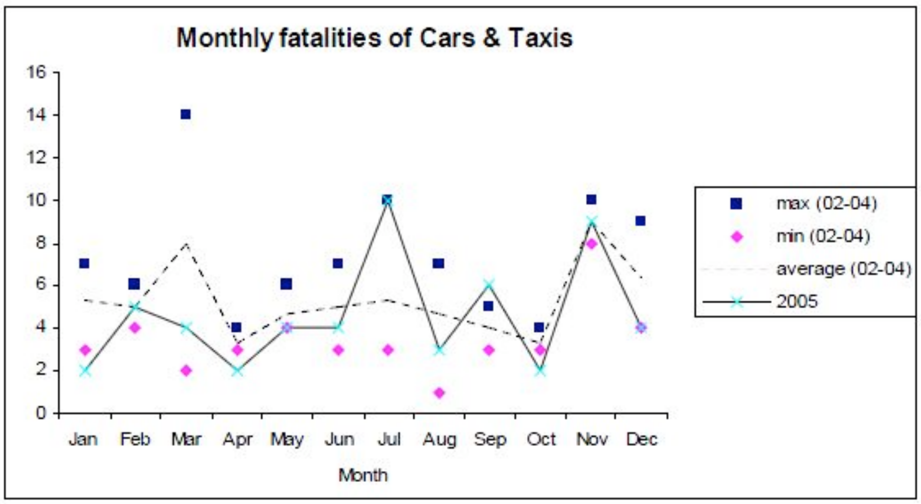


Among the three potential substitute modes of underground and bus, only pedal cycle shows a salient increase in fatality in 2005 compared to the years before as well as after.

Figure 6: London Monthly fatalities for Pedal Cycles, Powered-two-wheelers and Cars & Taxis.







The solid and dashed lines show respectively the fatality of 2005 and the three-year average between 2002 and 2004. The squares and diamonds are respectively the maximum and the minimum month fatalities between 2002 and 2004.

The top panel of figure 6 shows that, despite the overall high fatalities in pedal cycles in 2005 (the solid line of the top panel) compared to the previous three years (the dashed line), this increase had already started to take place before the bombings. The fatalities in April, May and June 2005 were either the same as or higher than the maximum fatalities for the same month between 2002 and 2004. Therefore, there is no reason to believe that the increase in fatalities was due to the bombings alone. An alternative way to capture this is to compute the '6-month fatality ratio', or the total fatalities in the second-half (between July and December) divided by the total fatalities in the first-half (between January and June) of each year. The result is shown in Table 3.

Table 6: Six-month fatality ratios (Jul-Dec/Jan-May) between 2002 and 2005

	2002	2003	2004	Average (02-04)	2005
Pedal Cycle	150%	90%	100%	113%	91%
2-wheeled motor vehicles	136%	103%	135%	125%	144%
Car & Taxi	117%	91%	104%	104%	157%

Table 6 shows that the 2005 fatality ratio for pedal cycles is actually smaller (91%) than the average of the three previous years (113%). It follows that the increase in fatality in 2005 was mainly due to the increase in the first half of the year, prior to the London bombings. A second insight from this analysis is that while there is no evidence for an increase in fatalities in 2005 for powered-2-wheelers and cars and taxis, this is perhaps because the fatalities decreased significantly a lot in the first-half of 2005.

Results Summary

Our analyses reveal that following the 7/7 bombings, Londoners avoided underground, and, most likely, buses - the two modes of transportation directly hit by the terrorists. Londoners thus showed 'dread avoidance', much like American citizens after 9/11 (Gigerenzer, 2006) and Spaniards following M/11 (López-Rousseau, 2005). Like Gigerenzer and unlike López -Rousseau, we find evidence for travel mode substitution, evidenced by the increased use of pedal cycles and powered-2-wheelers in 2005 compared to 2004 and 2006. However, unlike Gigerenzer, we find no evidence that fatalities increased as a result of avoidance and substitution. Thus, our data fail to support the notion that as a result of avoiding the dread risk, Londoners suffered a greater loss of life. This is a surprising result, because it shows that Londoners behaved differently from American as well as Spaniards. In the next sections, we offer some plausible explanations for this.

Discrepancy between 7/7 and M/11

First, we turn to the discrepancy between 7/7 and M/11. This is unexpected, given that both 7/7 and M/11 were attacks on ground transportation, and that both Britain and Spain are comparable on the characteristics proposed by López – Rousseau (lack of car culture, efficiency of public transport, history of terrorism). So, why did substitution occur in London and not in Madrid?

In addition to our findings and those of Gigerenzer (2006), avoidance and substitution were found, as far as we know, in only one other comparable study (Becker & Rubinstein, 2004). This study found that an attack on a bus in Israel caused a 30% reduction of bus traffic in the first and second month. At the same time Israelis used taxis more frequently after the attacks; that is, there was substitution. We therefore think that the surprising result is the lack of substitution found in Spain, which we attribute to the different methodologies employed by us vs. López-Rousseau. First, López -Rousseau analyzed countrywide, rather than city level, data, as we did. His choice was motivated by the need to compare the results with Gigerenzer's, who examined US-wide travel response. We on the other hand focused on London-wide data – a necessary choice given that the terrorist attacks were concentrated on London public transport. In our future research, we aim to collect UK-wide data on traffic and fatalities, to allow for a direct comparison with the Spain-wide data. Second, López -Rousseau assumed that the substitution mode for train was car travel. Again, this choice was motivated by the need to compare his results with Gigerenzer's, which examined highway traffic. By contrast, we collected data on all transportation modes, ruling out the unlikely ones (e.g. boat, airplane), before focusing on the three most likely substitutes to underground and buses as the means of transportation within London.

A second crucial factor that distinguishes Londoners' transportation choice is the fact that Londoners' travel behavior was heavily influenced by the congestion charge levied against anyone who drove private vehicles into the congestion charge zone, which covered most of the central London area (Zone 1) where the bombings occurred. This charge was originally introduced in February 2003 at a daily price of £5 and later increased to £8 on July 4, 2005, just 3 days before the bombings. This measure was taken to alleviate congestion within central London. The effect of the congestion charge on Londoners' reactions cannot be ignored, and, while current analysis cannot tease out its direct effect, we have reasons to believe that it has powerfully shaped how Londoners reacted to the bombings, and in particular their willingness to substitute means of public transportation.

The congestion charge is likely to have decreased the benefit and increased the perceived cost of substituting dreaded risk (underground or bus) with car. As a result, we expect the substitution from underground and bus to car to be limited, while substitution to non-chargeable vehicles, e.g. pedal cycles and powered-2-wheelers to be more likely. This is what Table 4 shows: the initial introduction of the congestion charge in 2003 led to a large increase in the use of non-chargeable modes (i.e., taxis, buses and coaches, powered two-wheelers, pedal cycles), and decreases in the use of chargeable modes (cars, vans, lorries, etc.) This impact was further enhanced, when, just three days before the bombings, the charge increased from £5 to £8, producing an even larger incentive for people to *continue* using the underground and buses, or to use non-chargeable vehicles instead.

Table 6: Key year-on-year changes in traffic entering the central London charging zone during charging hours (07.00 – 18.30)

	Change in inbound traffic				
Vehicle type	2003 vs 2002	2004 vs 2003	2005 vs 2004	2006 vs 2005	200(vs 20(
All vehicles	-14%	0%	-2%	0%	-16%
Four or more wheels	-18%	0%	-3%	0%	-21%
Potentially chargeable	-27%	-1%	-3%	+1%	-30%
- Cars and minicabs	-33%	-1%	-3%	0%	-36%
- Vans	-11%	-1%	-3%	+2%	-13%
- Lorries and other	-11%	-5%	-4%	+6%	-13%
Non chargeable	+18%	+1%	-4%	-1%	+16%
- Licensed taxis	+17%	-1%	0%	-3%	+13%
- Buses and coaches	+23%	+8%	-4%	+3%	+25%
- Powered two-wheelers	+12%	-3%	-9%	0%	0%
- Pedal cycles	+19%	+8%	+7%	+8%	+49%

Source: Transport for London

Consideration of the congestion charge allows us to better interpret the magnitude of the increase in pedal cycles traffic following 7/7. This magnitude (11.85%, see Fig 3) is even larger than the increase in 2003 (7.97%), when the congestion charge was first introduced. We are therefore confident that pedal cycles and two-wheeled motor vehicles, and in particular pedal cycles, served as the substitutes for the tube and buses. In summary, the congestion charge could have influenced both Londoners' willingness to substitute and the choice of substitute. It explains why car was not a substitute, unlike pedal cycle and powered-2-wheelers.

Discrepancy between 7/7 and 9/11

The second surprising finding pertains to the fact that substitution meant higher fatalities in the US (after 9/11), but did not mean increased fatalities in London. We explore the following four explanations for this discrepancy:

1) Could substitute modes used by Londoners have been *less* risky than the modes attacked (i.e. underground and buses)?
2) Could fatalities have increased in some areas but not others?
3) Could casualties, instead of fatalities, have increased?
4) Could fatalities have been prevented by the congestion charge or other London-specific policy measure?

Explanation 1

One reason why fatalities might not have increased in London could be that the substitute modes chosen by Londoners are less risky than the modes avoided. To determine this, we measured the *fatality rate* of each transportation mode used as a substitute. This rate is the ratio between the yearly fatalities divided by the yearly traffic volume of each mode. Table 7 presents the result.

Table 7. Yearly fatality rate in persons killed per million vehicle kilometers

	2002	2003	2004	2005	2006
Pedal Cycle	0.0398	0.0351	0.0153	0.0359	0.0302
Powered 2-wheeler	0.0866	0.0729	0.0581	0.0521	0.0522
Car & Taxi[13]	0.0028	0.0024	0.0021	0.0021	0.0023

Source: Transport for London

In comparison, the yearly fatality rate of the modes directly attacked were extremely low: 5, 9 and 4 fatalities occurred on the London underground in 2002, 2003 and 2004[14] whereas the numbers of fatalities for buses and coaches are 7, 5 and 4, respectively. The traffic volumes of buses and coaches are larger than that of pedal cycles or powered-2-wheelers (Fig.2 and Table 2), and it is reasonable to assume that Londoners travel more often as well as in longer distances by underground than by bike. As a result, the fatality rates of the two affected modes are likely to be lower than pedal cycle and powered-2-wheelers. That is, the substitution modes chosen by Londoners are riskier than the modes avoided – just like in the US, suggesting that this explanation does not hold. Indeed, we find that the fatality rates of all three transportation modes are lower in 2005 than those in 2002 (Table 5). The decrease in powered-2-wheelers is the largest. That is, the roads are becoming safer to use.

[13] Judged from the fatality rate, these data seem to suggest that cars are safer than buses. This seems to be a counter intuitive result. The reason is that London Taxi is the safest transportation mode, incurring only 1 fatality over the four years between 2002 and 2005. We are unable to separate fatality rates for car and taxi because the traffic volume data are only available for the sum.

[14] London underground fatality data are based on financial rather than calendar years, i.e. from 05 April each year to 04 April of the following year.
http://www.tfl.gov.uk/assets/downloads/safety_plan_2005.pdf, last accessed on 4, July, 2008.

In the most recently published yearly review of the impact of congestion charging[15], this improvement in road safety was attributed to the London- wide road safety initiatives over the recent years. In addition to these, *Transport for London*, the government body responsible for most aspects of the transport system throughout London, also introduced interventions including assisting pedestrians and cyclists at junctions and bus priority measures. These, incidentally, might be another reason why (1) road fatality decreased in the period examined, (2) car travel failed to increase after the bombings, (3) bus patronage did not fall in 2005 and (4) pedal cycles increased robustly since 2004.

Explanation 2

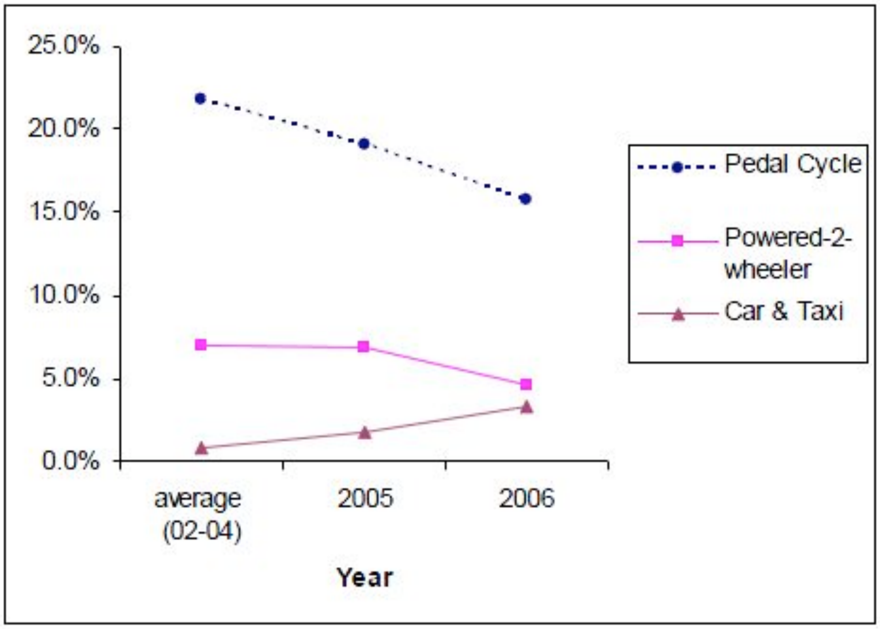
A second reason why we do not find an increase in fatalities London-wide could be that we aggregated fatalities across boroughs. Would a different picture emerge if we collected fatality data by borough and compared the fatalities of boroughs directly exposed to the bombings and boroughs not directly exposed? We addressed this by considering the fatalities of the substitute modes (pedal cycles and powered-2-wheelers) for each of the 33 London boroughs separately. Next we aggregated the data for the three directly hit boroughs (Camden, City of London and City of Westminster). Last, we computed the share of the fatalities of these three directly affected boroughs to the London total. The results are presented below.

	2002	2003	2004	Average (02-04)	2005	2006
Pedal Cycle	30.0%	10.5%	25.0%	21.84%	19.0%	15.8%
Powered 2-wheeler	1.5%	11.1%	8.5%	7.05%	6.8%	4.7%
Car & Taxi	2.6%	0.0%	0.0%	8.77%	1.8%	3.3%

As shown in Fig.7, for each of the three transportation modes, the shares of 2005 fatalities of these three directly hit boroughs were always bounded by the one in 2006 and the average of the previous three years, from 2002 to 2004. Hence, there is no evidence that the fatalities increased in these boroughs in 2005. On the contrary, in these boroughs the share of fatalities of the two substitute modes, i.e. pedal cycles and powered 2-wheelers, actually decreased in 2005 compared to 2004.

[15] http://www.tfl.gov.uk/assets/downloads/fifth-annual-impacts-monitoring-report-2007-07-07.pdf. Last accessed: 04 July, 2008.

Fig.7. ***%*** **share of the fatalities of the three directly-hit boroughs to the London total.**

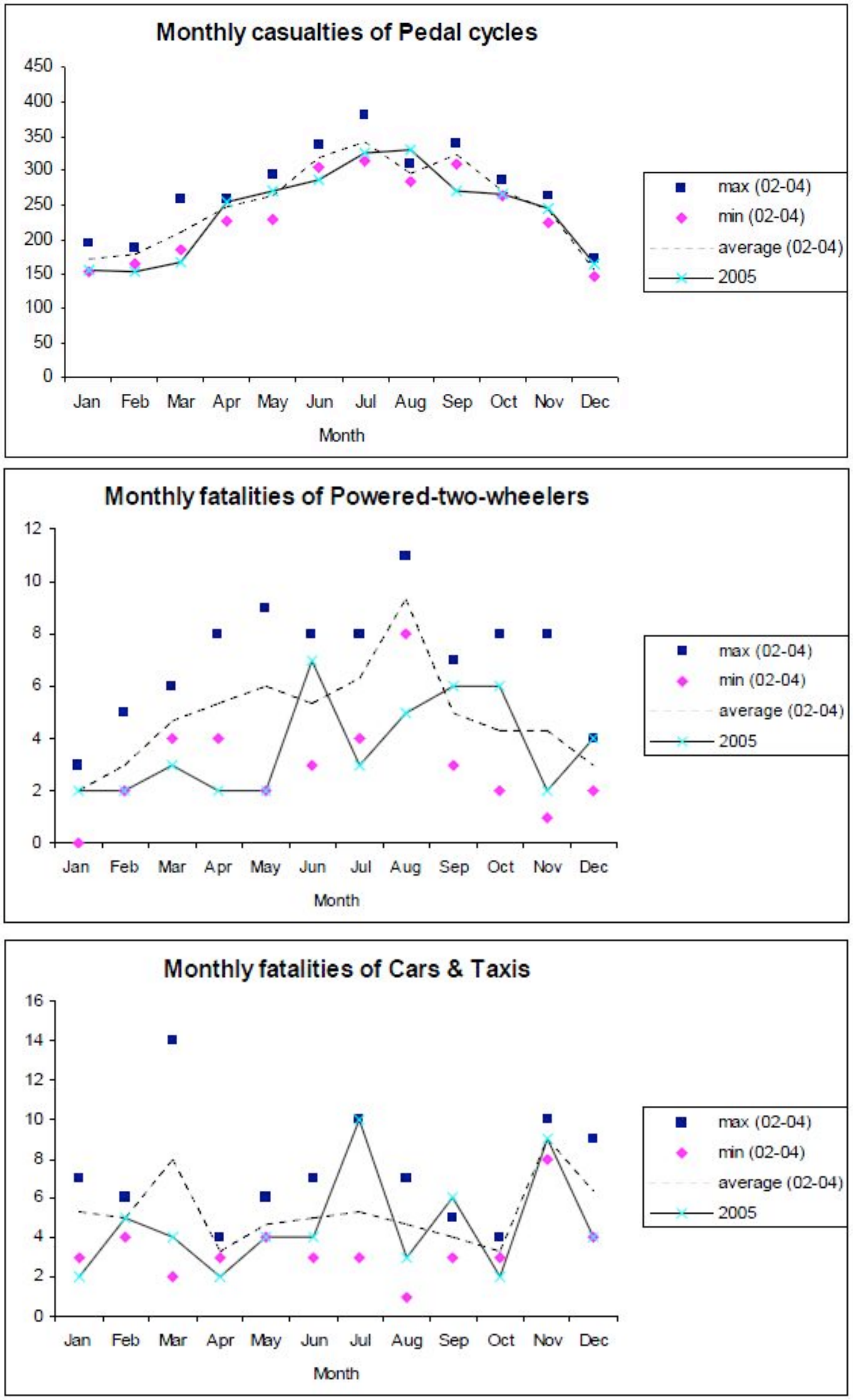


Explanation 3

As Gigerenzer and López-Rousseau, we also used fatality data to assess whether the London bombings imposed a second indirect damage in terms of substation-induced fatalities. We found no evidence for an increase in fatalities due to the increased use of pedal cycles and powered-2-wheelers. A possibility, explored here, is that substitution led to an increase in road accidents but – perhaps due to the policy aimed at improving road infrastructure – these accidents did not kill. To test this we analyzed casualties (not fatalities) by transportation mode (pedal cycles, powered-2-wheelers, cars and taxi).

As shown in Fig.8, casualties of powered-2-wheeler and car and taxi are *below* the minimum value of the previous three years (2002 to 2004). This is the case both before and after July 2005. A different and interesting case is offered by pedal cycle. Following 7/7, there was indeed an increase in pedal cycle casualties in August 2005, *above* the minimum of the previous three years. When computing the 6-month casualty ratio (i.e. dividing the number of casualties in the second-half of a given year by the number of casualties in the first half of the same year), we see that this ratio was 1.09, 1.16, and 1.11 for 2002, 2003, and 2004. In 2005, the ratio was 1.13, similar to 2006, when it was 1.14. Hence, there is no reason to believe that the casualties were abnormally high in the second half of 2005.

Fig.8. Monthly casualties of Pedal Cycles, 2-wheeled motor vehicles and Cars & Taxis in London.



The solid and dashed lines show respectively the casualties of 2005 and those of the three-year average between 2002 and 2004. The squares and diamonds are the maximum and minimum fatalities in each month of 2002 and 2004.

Explanation 4

Londoners' substitution of public transport with pedal cycles shows that Londoners had both a heightened perception of the dread risk (or else they would have continued using public transport) and awareness of the costs of substituting underground and bus with chargeable private transport (or else they would have substituted with cars and taxis more, as Becker and Rubinstein).

The absence of substitution-induced fatalities is in our view closely linked with London roads becoming safer due to Governmental action. While these policy effects create a challenge in the data analysis of this project, they also offer an unprecedented opportunity to learn from a 'social experiment'. In particular, the London experience suggests that one way for Governments to mitigate citizens' reactions to attacks perpetrated by terrorists on public transport is to enhance the attractiveness of safer transportation substitutes (or, alternatively increase the relative cost of riskier modes e.g., charging for car travel) as well as to provide a better public transportation system which decreases the chance of substitution-induced fatalities.

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The impact of the 3/11 Madrid bombings on consumers travel behavior

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Introduction

Madrid, march, 11 2004. At 7:39 three rucksack bombs explode in a train entering *Atocha* station, Madrid. In quick succession, they are followed by four more bombs in a train in the *Calle Téllez*, another on a train that stationed in Santa Eugenia Station and two more explode in a train near the *Pozo del Tío Raimundo*. Spain was duffering the worst terrorist attack in its history.

In the early morning no-one in Spain doubted that it was ETA (the Basque terrorist group *Euskadi ta Askatasuna*) who were behind the massacre,[16] a fact that was made clear in the rapid succession of institutional and political party statements condemning the attacks and attributing responsibility to ETA.[17] Only a few experts detected details which made ETA participation unlikely, but for the moment these were mere intuitions, which were rejected when the Police told the government that the explosive used was *Titadine,* which was that normally used by this terrorist group. Though it was true that the spokesman for the illegalised *Batasuna* —the political arm of ETA— attributed the attack in an early morning radio interview to 'agents of sectors of the Arab resistance' (sic), this hypothesis was rejected by the government, when CNI (the Spanish Intelligence Service) intercepted a call from the same *Batasuna* spokesman stating that: 'We must play for time. Meanwhile, we must blame the Islamists, later on we'll see'. Yet, these statements were not sent out by the press agencies till 12:05; some twenty minutes before, the Government had announced the fact that there were already more than 100 victims.

Nevertheless, the statements by Interior Minister (Mr Acebes), confirming 'without any doubt' —and on the basis of information received by State organisations and Security Bodies— that ETA had been responsible, was backed up almost

[16] For a detailled anaysis of the events, see Baumert (forthcomming), García-Abadillo (2004) and Álvarez de Toledo (2004).

[17] Although untypical for a research paper, the personal experience of the author might be relevant for the purposes of this study. The day of the Madrid bombing I went to work as usually, taking both the metro and bus. That precise morning I a had a meeting with other members of what has later become the Research Team of the Chair of the Economics of Terrorism of the Complutense University of Madrid, and of course the main —not to say the only— topic discussed was the attack and its consequences. At that moment all of us were convinced that it was ETA who had perpetrated the attack, as the *modus operandi* was identical to the failed attempt of ETA to blow up a train on New Year's Eve. As usually, I went back home taking again the bus and the metro, as I hadn't taken the car that morning.

immediately by the leader of the Popular Party who indicated that ‘everything points to it having been ETA‘ and freshly confirmed by President José María Aznar at 14:30. However, in this case no specific mention was made of ETA.

Indeed, the Government had a series of strong arguments —which were conveniently passed to the press— that gave support to ETA being the perpetrators. According to the State Security corps and forces, the explosive found on the trains was *Titadine* dynamite, the type normally used by ETA and the police were well aware of ETA’s intention to launch an attack precisely in that week. Since the end of the truce in 1999, ETA had attempted on four previous occasions to perpetrate a massacre similar to the one in Madrid, the last of them barely three months before (on New Year’s Eve), by placing two suitcase bombs on the Irún-Madrid Intercity; and the CNI had intercepted calls from members of ETA claiming responsibility for ‘the firm’.[18] Consequently, at three p.m. the CNI continued to state that ‘almost certainly the terrorist organisation ETA is the author of these attacks’. This hypothesis was given support, moreover, by the fact that neither the CIA, nor MI6, nor the Mossad were able to confirm that their agents had detected any noise from Al Qaeda in relationship with an attack in Spain. Only the German government, basing their opinion almost undoubtedly on BND data, appeared reluctant to consider the attacks as the handiwork of ETA. Nevertheless, the discovery of a van abandoned by the terrorists, in which a tape was found with verses from the Koran and a box of detonators, gave fresh strength to the arguments pointing against ETA responsibility: the detonators were not of the type used by the terrorist band, but, rather, *Antigrisú*, and the remains of explosives found in the van were not *Titadine* but *Goma2*.

These facts once more reinforced the thesis sponsored by some sceptics during the early morning; it was not the habitual *modus operandi* of ETA, who before an indiscriminate attack usually give warning. in fact, the suitcase bombs on New Year’s Eve, 2003 had inside a radiocassette with a tape that was supposed to give a warning of the attack minutes before the scheduled explosion — even though it would have been of no use, as the ETA terrorists had forgotten to put batteries in it.
Thus the day ended with two certainties that put an end to the speculations of the morning: the final number of dead raised from 173 to 182 and the spread of rumours (about the tape with verses from the Koran found in an abandoned van) pointed definitively to an attack perpetrated not by ETA, but by a Jihadist terrorist cell.

Passenger’s reactions to terrorist attacks on public transport services: an overview

Among the growing literature about the economic and sociologic impact of terrorism, many authors have centred their attention among the repercussion of terrorism on consumer’s transportation mode choice and transportation habits (see, among others, Beeler and Clemens, forthcoming; Blalock, Ito and Lee, 2005; Kadiyali and Simon, 2005; Plant, 2004 and Sivak and Flannagan, 2003; Stecklov and Goldstein, 2004).

Nevertheless, the starting point for this research lies in the article by Gigerenzer (2005) (relying on Myers, 2001) on in which he stated his “dread

[18] Curiously, this fact is often overlooked and little known outside Spain, although it might be relevant to understand consumer reaction, as we will show later on.

hypothesis" according to which after 9/11 Americans reduced the mode of the transportation mode directly affected by the attacks —in this case planes— increasing instead substitute transportation alternatives (like cars or trains). Depending on the implicit fatality risk of the substitution mode, this could result in higher fatalities that might have occurred using the original transportation mode.

Indeed, Gigerenzer found that immediately following the, the number of fatal crashes rose above the five-year maximum (1996-2000) for each month and remained so for as period of six months. Thus, according to the authors findings, terrorists would in fact strike twice, first physically on people and infrastructure, and the psychologically, through people minds. This result derives in important consequences, as "avoiding the second, psychological motivated toll could be comparatively easy and inexpensive, if the public were better informed about psychological reactions to catastrophic events, and the potential risk of avoiding risk" Gigerenzer (2004:287).[19]

The Madrid experience

Unlike what happened in the London and Tokyo attacks, the Madrid bombings were perpetrated against interurban (short distance) trains. Thus, intra-urban transportation modes, like buses and Metro (except for one Underground line as explained in point 3.2) were not directly affected and could have even experienced (together with other transportation forms like cars) a shift as a substitution for the former.

The aim of this paper is to explore to which extend —if at all— the terrorists attacks of 3/11 affected consumer's behaviour towards public transportation modes, taking into account both the possible size and the duration of the impact. The analysis is done more in depth for the Metro (Underground) and for the Bus, as this were finally the only two data sources we were able to obtain disaggregated at a daily level. Additionally, we also take a brief look at other transportation modes such as trains and cars.

As we have already mentioned in the previous section, López-Rousseau (2005) showed that after the Madrid bombings Gigerenzer's (2004) "Dread Risk Hypothesis" could not be proved true. Nevertheless, the analysis of the Madrid case is still relevant, especially in comparison with other similar experiences, as —unlikely the 7/7 bombings or the Tokyo Sarin gas attacks— it presents to specific characteristics:

- The attacks were perpetrated against interurban transportation modes. Both the London and Tokyo attacks were targeted against intraurban travel systems, similarly to what occurs in Israel.[20]
- Spain has been suffering continuous terrorist attacks for over thirty years now (mainly by ETA), thus the hypothesis may be set that Spaniards have accepted

[19] As we will see later on, the "dread risk hypothesis" was checked for the case of 3/11 by López-Rousseau (2005), evidencing that it could not be verified after the Madrid bombings.

[20] It might be worth remembering, that two years later (7/31/2006), the German Police found two suitcase-bombs in a regional train from Aachen to Hamm. Thus it seems that train-bombing is a recurrent form of terrorist plot (the New-Years-Eve attack by ETA, the Madrid bombings and the failed attempt in Germany), that reveals the strong need to improve security measures on railway stations in Europe (see for this also Plant, 2004).

a higher risk level, thus having a shorter and less intense reactions to terrorist attacks (again, similarly to what occurs in Israel).

Buses[21]

Although the attacks were perpetrated against interurban transport modes (trains), intra-urban transportation modes might be affected both negatively or positively by this fact, depending o whether consumers considered the terrorist risk affected all forms of public transport, or (considering a lesser fatality risk of the latter) shifted instead from trains to buses.

As we have pointed out before, when the information about the bombings spread through the media in the early morning, Madrilenians were immediately reminded of the failed ETA attacks of the previous New Year's Eve. Thus, we might state the hypothesis that they should have perceived 3/11 *a priori* as repetition of that attempt, and not as a general attack on different transportation modes.

Figure 1: Daily number of passengers Madrid Bus (9/1/2002-30/9/2004)

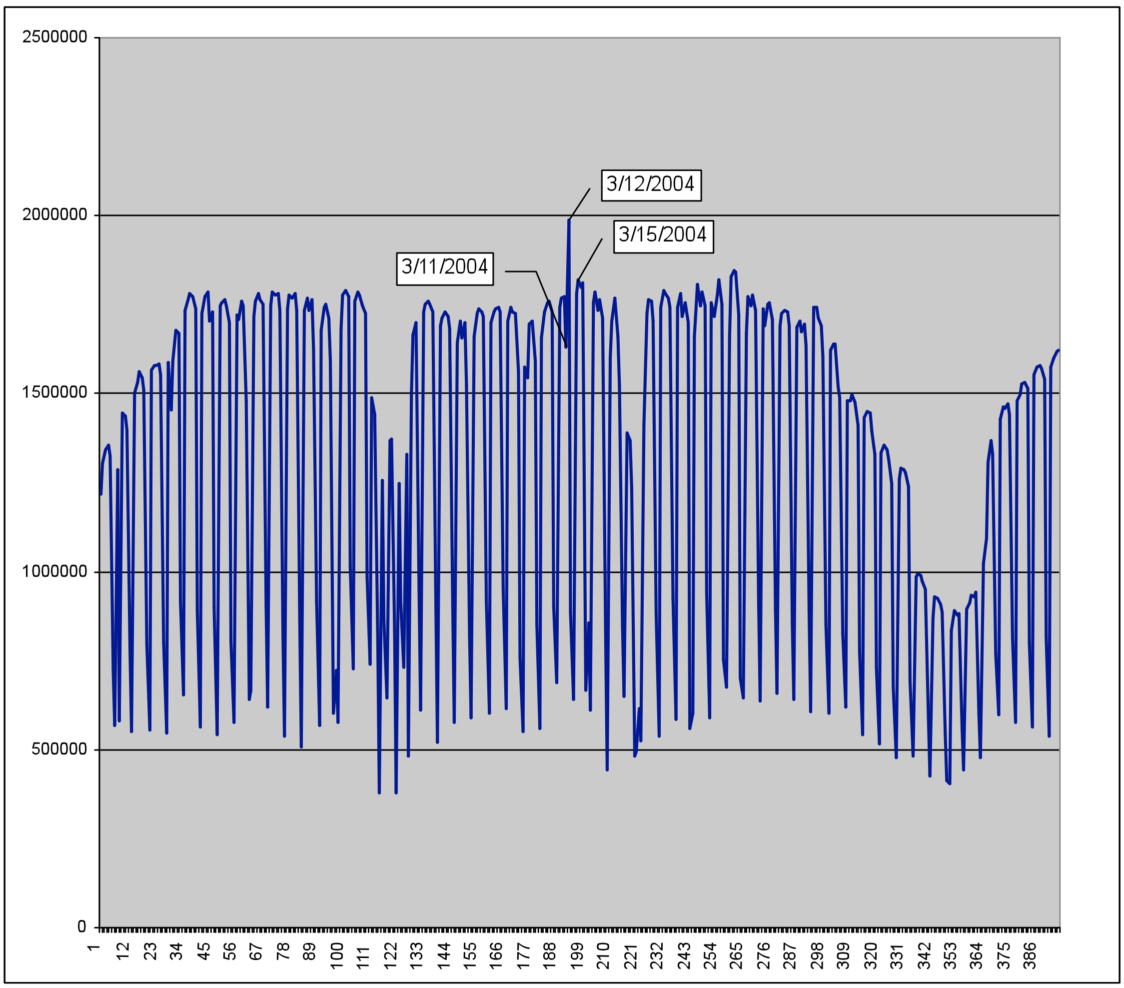

Figure 1 presents the daily number of passengers of the Madrid buses. Apart from the usual oscillations due to the descends of bus-users on weekends, the number

[21] The author thanks the EMT (*Empresa Municipal de Transporte de Madrid*) for their kind support to this research giving me access to the daily passengers data, an information which is normally not published.

of daily bus passengers stays relatively constant in the band around 3/11. Taking a closer look at it, we see that the number of Bus passengers decreased on Thursday, 3/11 to 1,629,172 (around 100,000 users beneath the average of the previous business-week), only to rise sharply on Friday, 3/12 to 1,990,050 passengers (around 160,000 users over the same average). This might be due to the fact, that on this day a massive demonstration of the citizens of Madrid took place in repulse to the attacks (a usual custom in Spain after every terrorist attack), thus requiring additional bus capacities to carry people from the outskirts to the city centre.[22]

It is also worth pointing out, that on Monday 15th, the day after the General Elections which outcome might have been significantly altered by the bombings (see for this among others, García-Montalvo, 2006) 1,781,837 bus users were registered, a number slightly higher than the average.

Figures 2 and 3 show the weekly distribution of Madrid Bus passengers between 2003 and 2006. The Madrid bombings took place in week 11, and it is seen in Figure 2 that on this level of aggregation there is no evidence of a decrease in the number of passengers, as the negative effect of 3/11 were compensated by the number of users of the three previous business days, which were above average. On the other hand, Figure 3 shows the same information but distinguishing the peaks due to the Eastern Holidays, which depend on the lunar calendar and thus are celebrated each year on different weeks.

In this context, it is important add that March 19th (Saint Joseph) is a free day in many regions of Spain, including Madrid. Especially in the region of Valencia, the "Fallas" also known as "Saint Joseph Feast" start three days earlier (on March 16th) and many Madrilenians use to take an (additional) free day to go to Valencia. This may account for a slightly decrease in the (potential) number of bus passengers in Madrid, although we have not been able to discriminate for this effect.

Summing it up, we may conclude that the Madrid bombings a significant but short effect on the number of bus passengers of Madrid. On 3/11 it decreased around 8 percent regarding the average of the three previous business days. Nevertheless this effect lasted only one day.

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[22] In order to allow a correct interpretation of the Figures included in this and the next sections, it should be noted that in March 2002, the 18th, 19th and 27th to 31st were free days; both in March 2003 and 2004 the 19th was free, while in March 2005 from the 21st to the 28th were holidays, In March 2006 Saint Joseph's day (19th) was swapped to the 20th.

Figure 2: Weekly distribution of Madrid bus passengers (2003-2006)

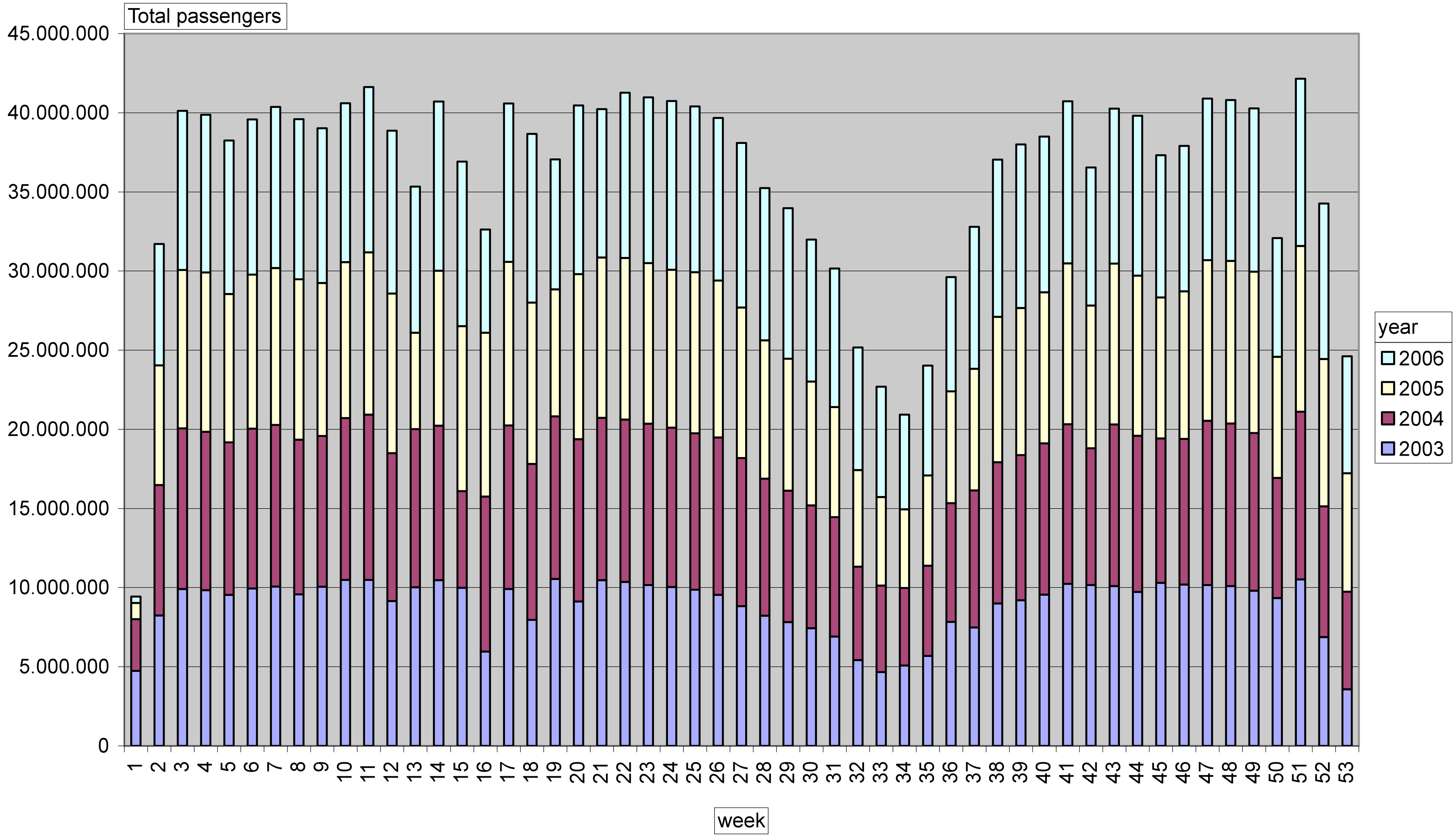
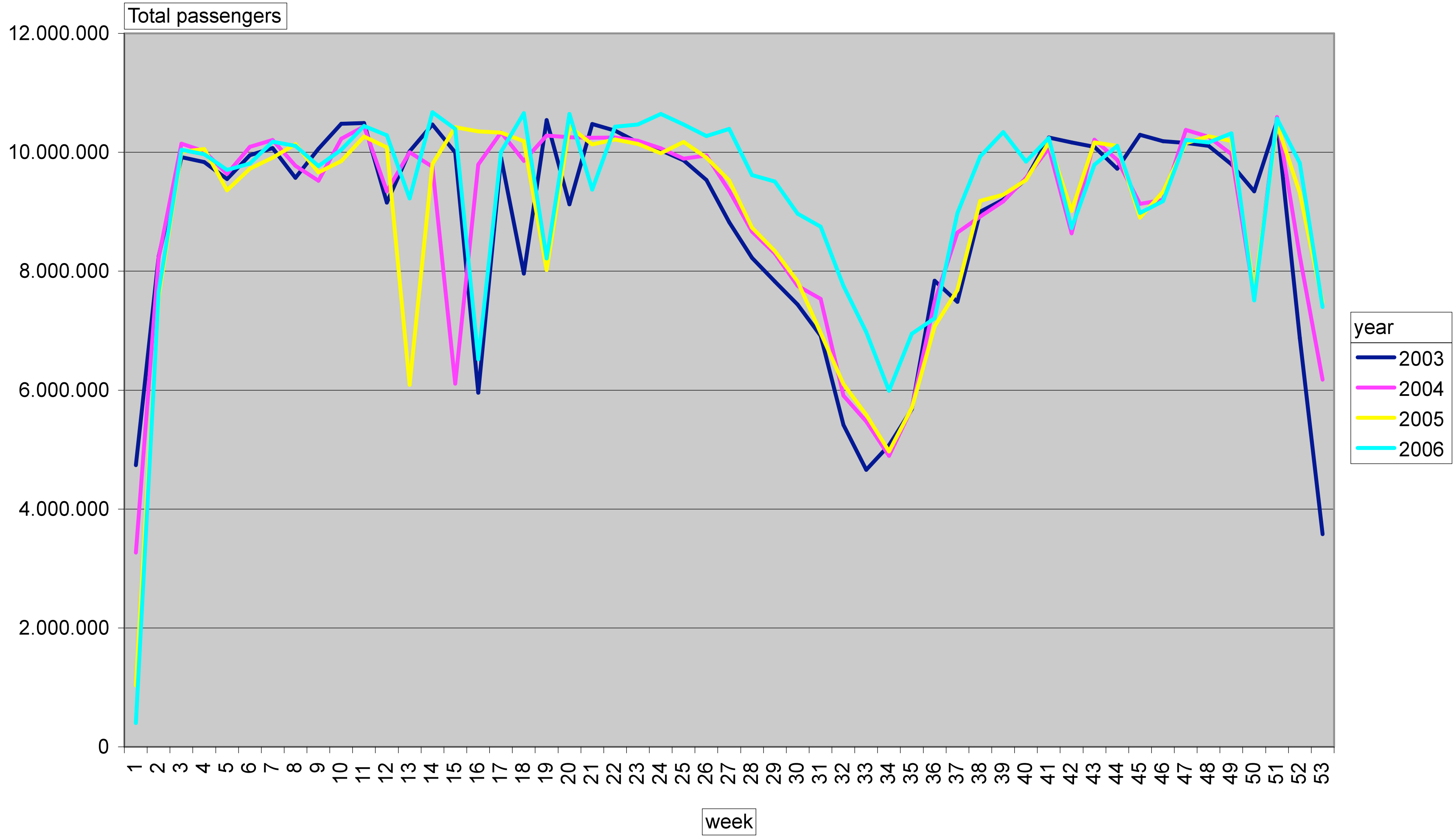


Figure 3: Weekly distribution of Madrid bus passengers (2003-2006)



Metro[23]

A second transportation mode to be considered is the Madrid Metro. Madrid has a very broad underground service that reaches to the outskirts of the city and could thus, have been used as an alternative for passengers who normally use the short-distance trains.[24]

Figure 4 shows the number of daily passengers during March for the range of years from 2002 to 2007 aggregated for all Metro-lines (there are twelve in total). The data has been adjusted to the first business day of the month in order to make working days and weekends fit. A first look allows to see that during 3/11 Madrilenians reduced significantly the use of the Metro. In fact, it only registered 1,809,066 passengers during that day, around 21 percent less than the average of the three previous working days. Nevertheless, and just as happened with the Bus, this reaction was a very short term one, as the next day (3/12) there is a huge peak of 3,240,116 passengers in all lines, the highest value experienced in any March of the years studied. Again, on Monday 15th, the number of passengers seemed to stabilize, although on a level slightly below the pre-bombings one.

Figure 5 shows the number of daily passengers of the Metro line N1 ("light blue", see appendix 1) for each March between 2002 and 2007). Again, the Figure has been adjusted to fit working days and weekends of each month. As this line was the only directly affected by the attacks (the entrance to the station is located precisely at *Atocha*, the place where the first three bombs exploded) it is specially relevant to the purposes of our study.

At a first glance we can see, that it presents a very similar behaviour than the previous Figure. Line 1 experienced an important decrease in the number of passengers on 3/11 and a high maximum the day after, as a result of the demonstration in repulse of the attacks. As already explained above, the demonstration in repulse of the attacks started at *Columbus Square* and ended at *Atocha*. This meant that the Metro lines with stations near this points were especially high on 3/12.

[23] The author would like to thank the Madrid Metro Company for their giving him access to the data and the kind permission to work with the daily data, an information that is usually not publisher nor given access to.

[24] Although Madrid has currently twelve Metro lines (see appendix 1), we only study here ten, since lines 11 and 12 started to work to full extend after 3/11.

Figure 4: Number of daily passengers Madrid Metro March (2002-2007)
<u>All lines</u> (Adjusted to first business-day of the month)

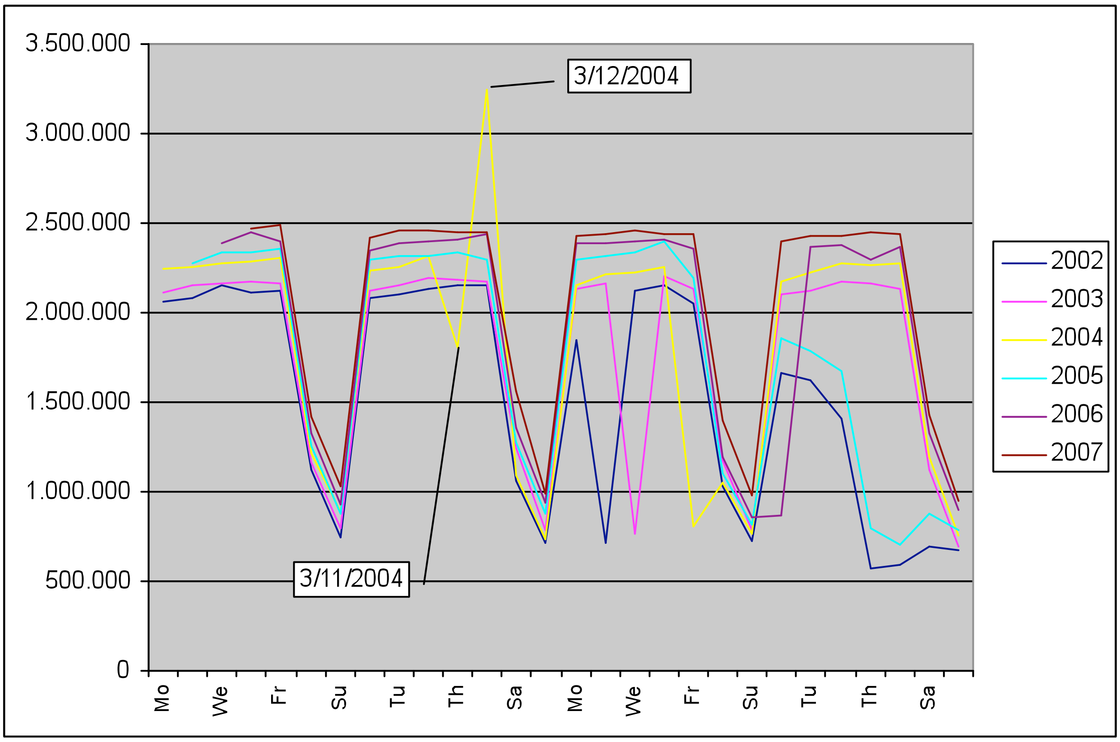


Figure 5: Number of daily passengers Madrid Metro March (2002-2007)
<u>Line N. 1 (light blue)</u> (Adjusted to first business-day of the month)

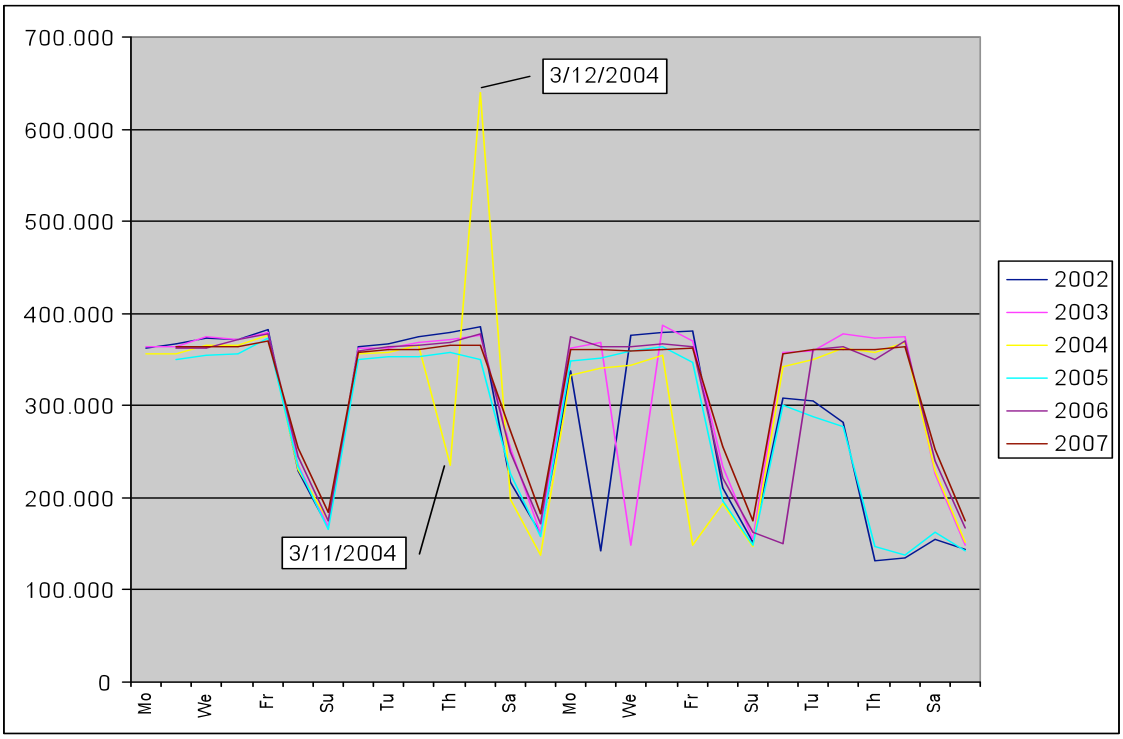


Figure 6: Number of daily passengers Madrid Metro March (2002-2007)
Line N. 2 (red) (Adjusted to first business-day of the month)

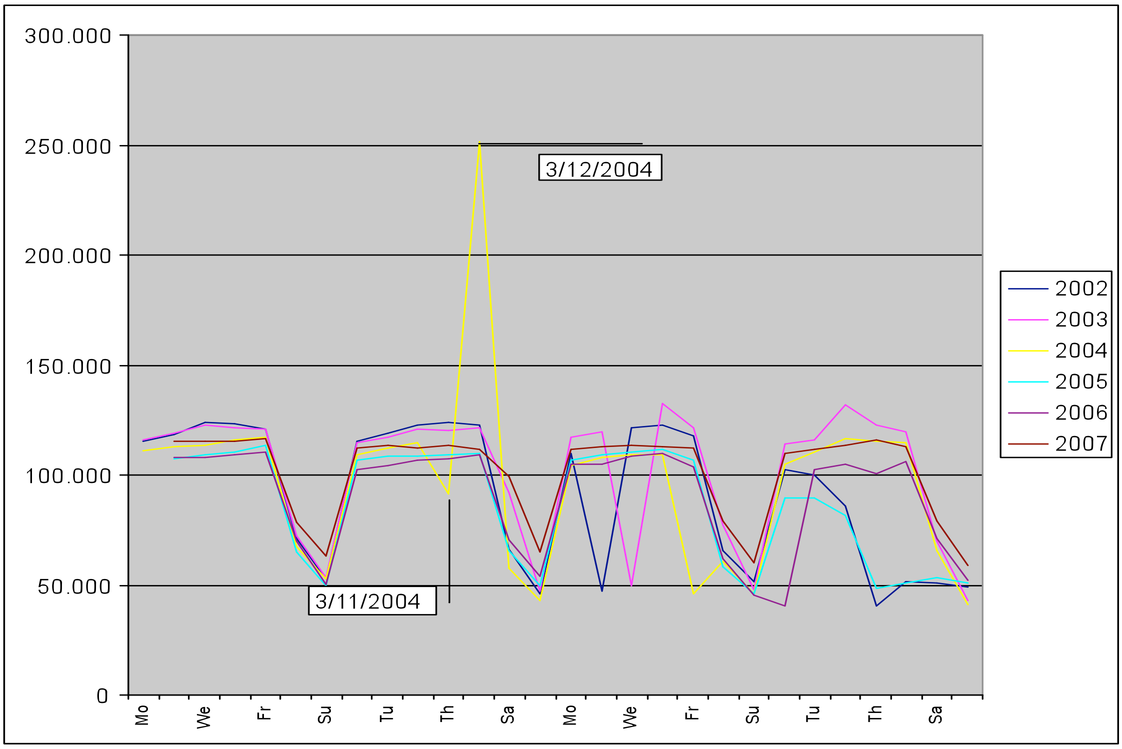


Figure 7: Number of daily passengers Madrid Metro March (2002-2007)
Line N. 3 (yellow) (Adjusted to first business-day of the month)

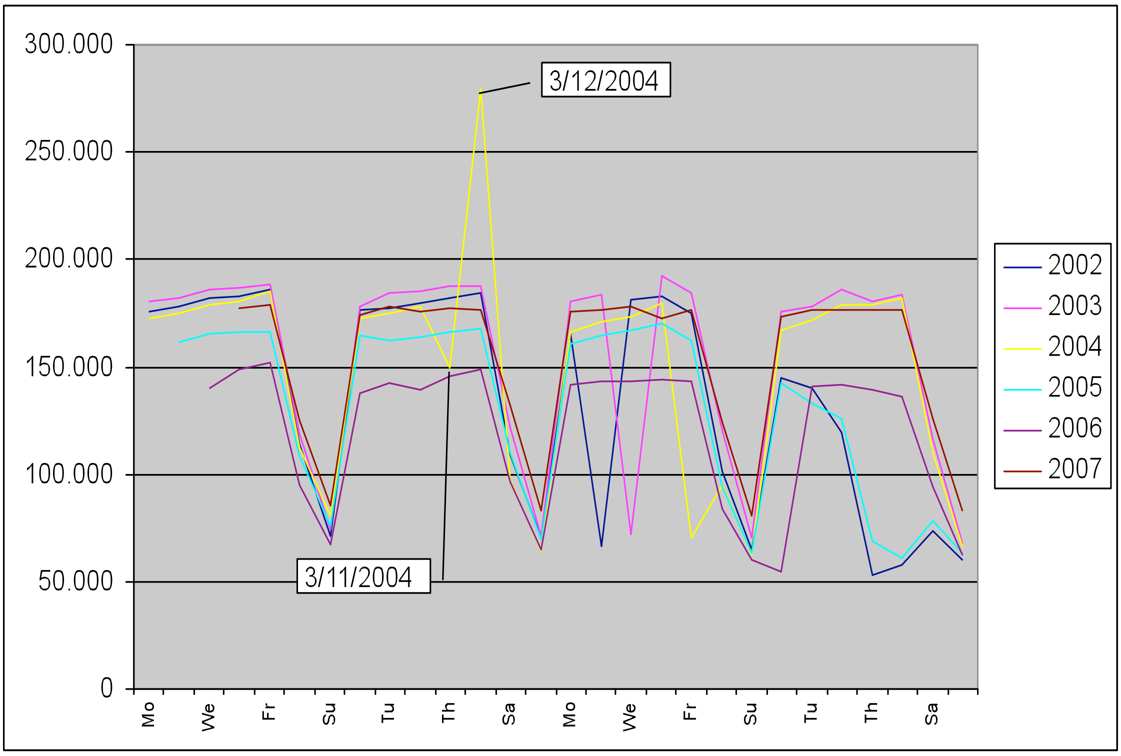


Figure 8: Number of daily passengers Madrid Metro March (2002-2007)
<u>Line N. 4 (brown)</u> (Adjusted to first business-day of the month)

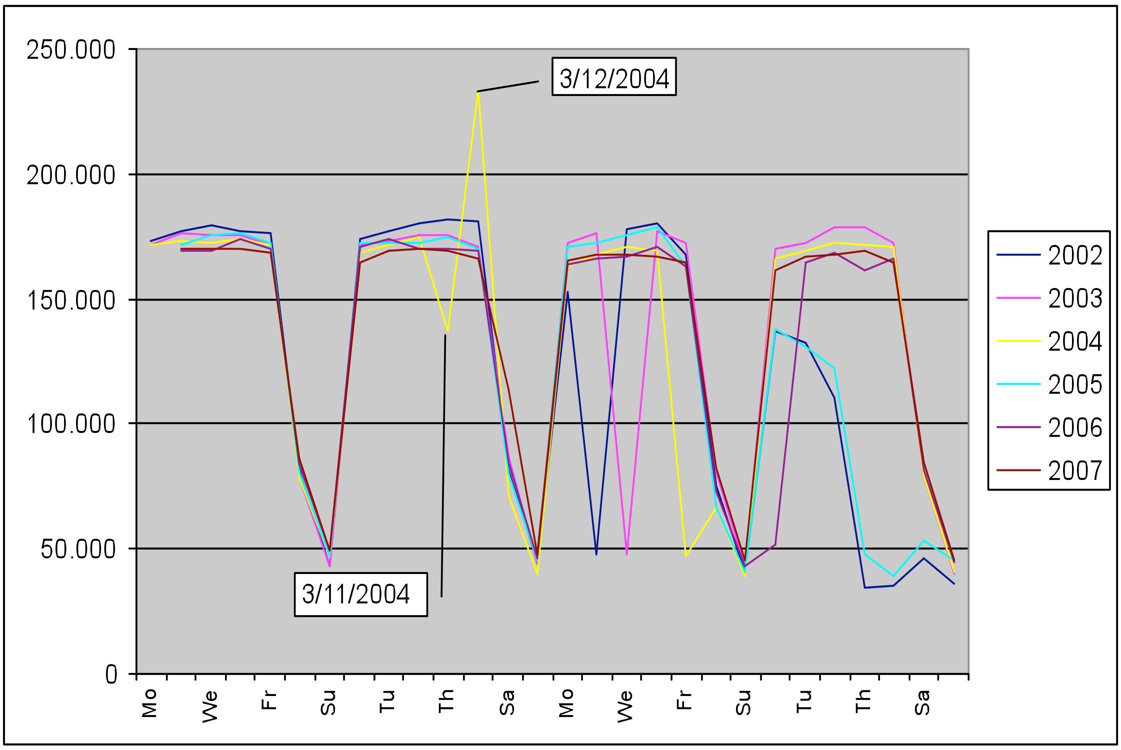


Figure 9: Number of daily passengers Madrid Metro March (2002-2007)
<u>Line N. 5 (green)</u> (Adjusted to first business-day of the month)

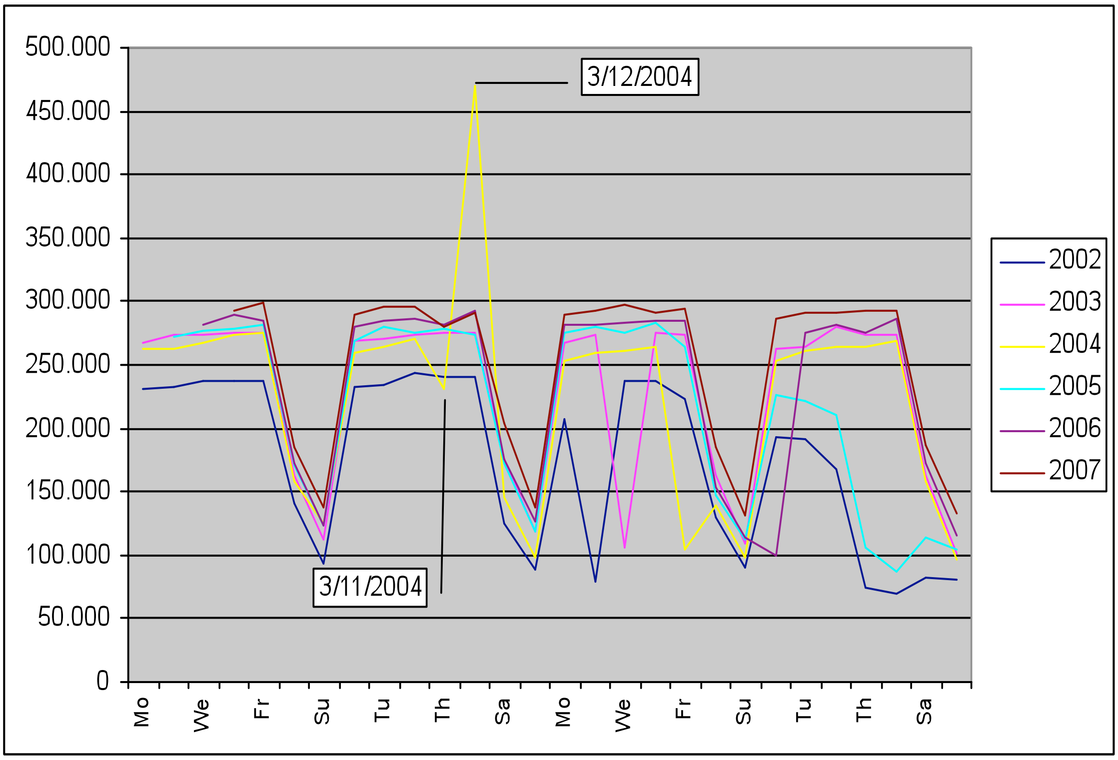


Figure 10: Number of daily passengers Madrid Metro March (2002-2007)
<u>Line N. 6 (grey)</u> (Adjusted to first business-day of the month)

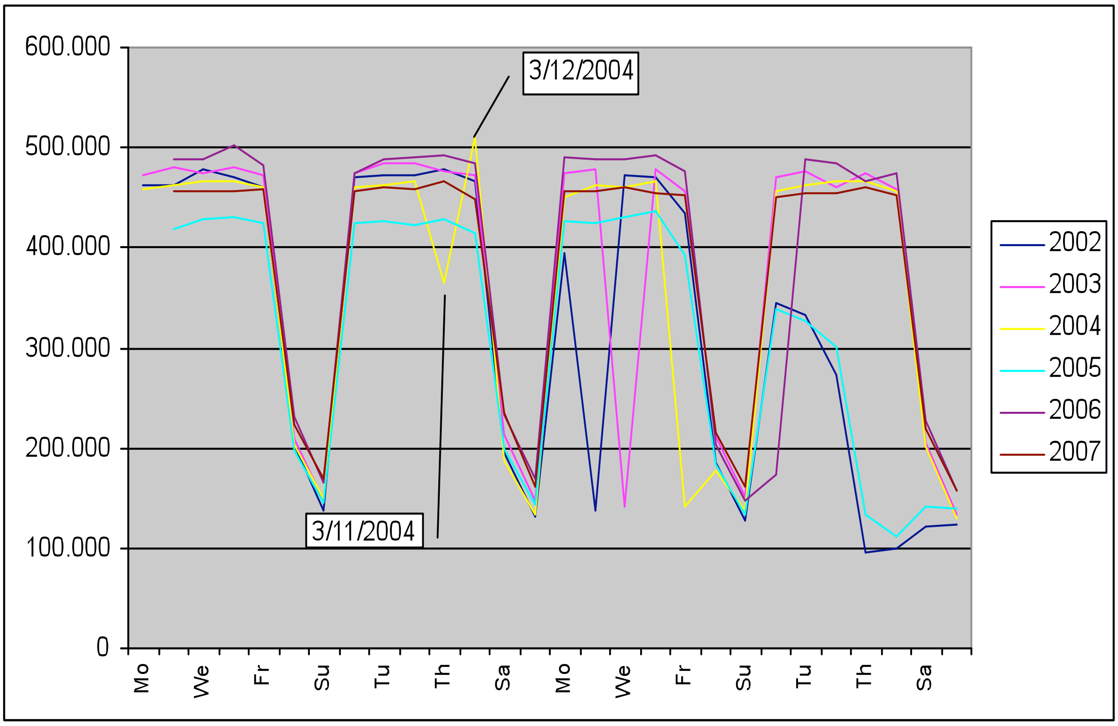


Figure 11: Number of daily passengers Madrid Metro March (2002-2007)
<u>Line N. 7 (orange)</u> (Adjusted to first business-day of the month)

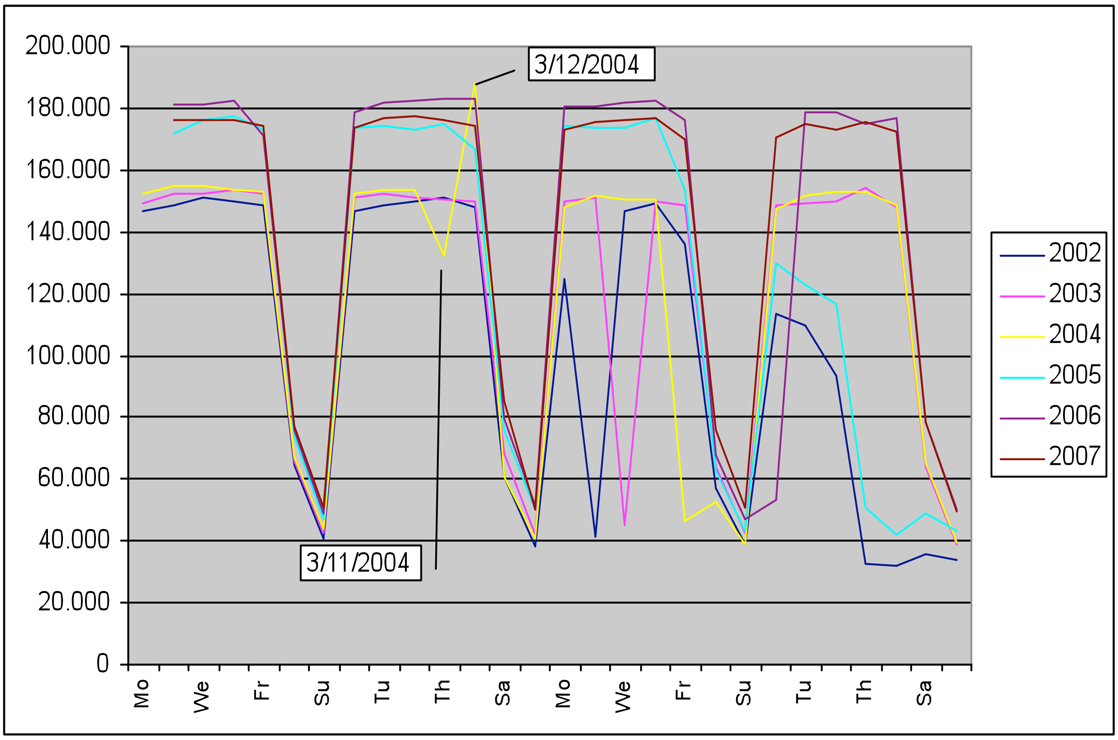


Figure 12: Number of daily passengers Madrid Metro March (2002-2007)
<u>Line N. 8 (pink)</u> (Adjusted to first business-day of the month)

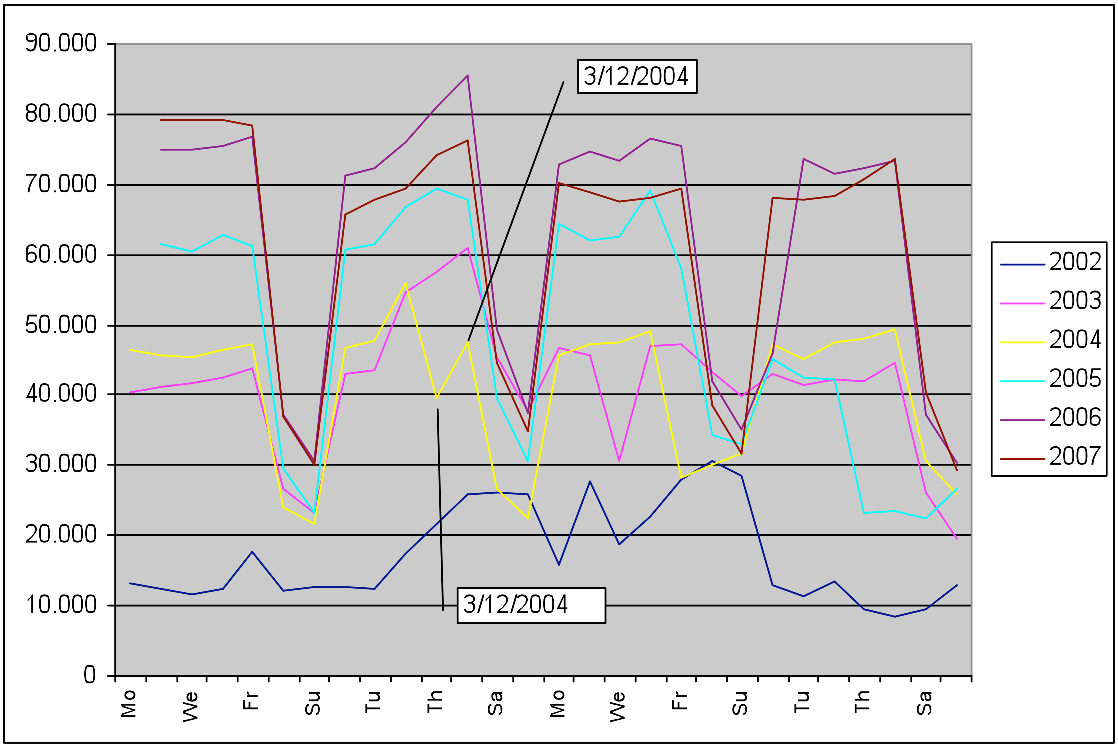


Figure 13: Number of daily passengers Madrid Metro March (2002-2007)
<u>Line N. 9 (violet)</u> (Adjusted to first business-day of the month)

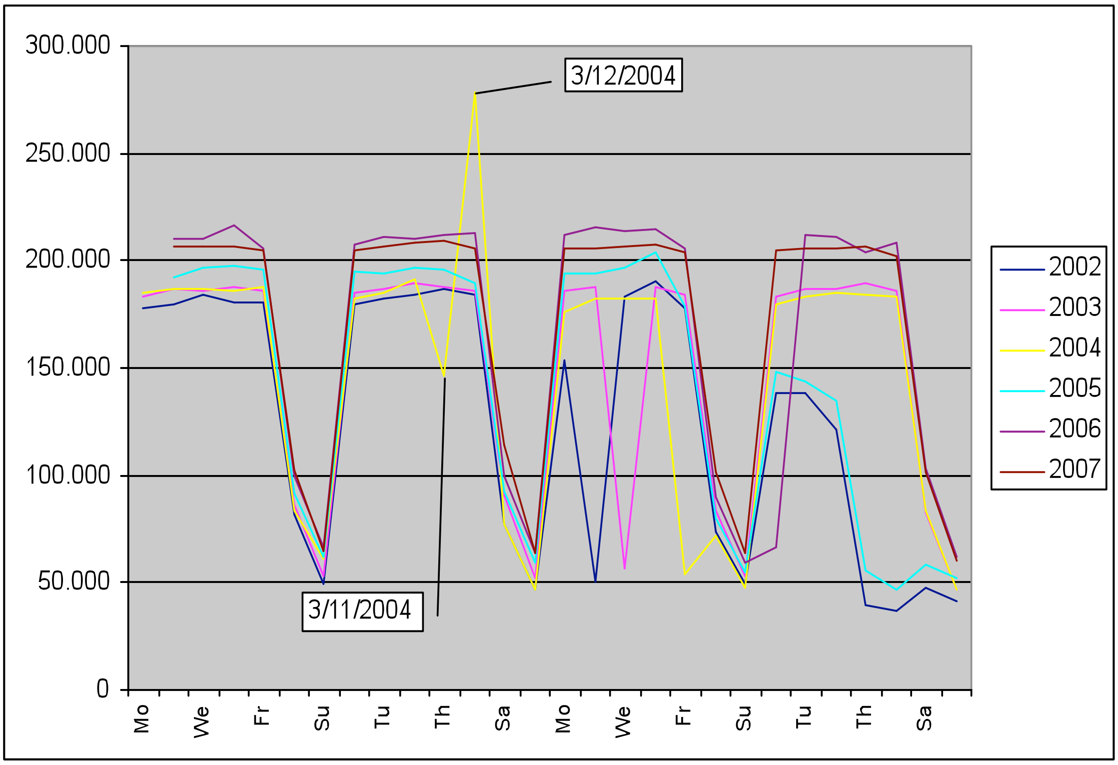
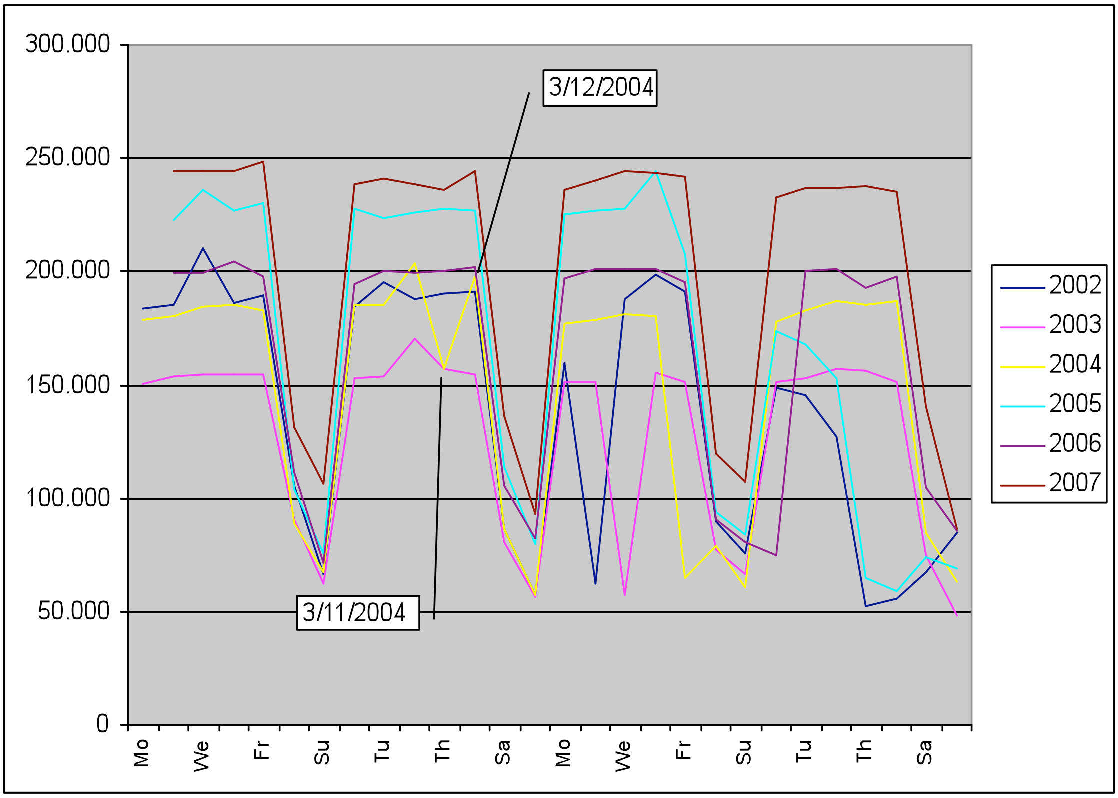


Figure 14: Number of daily passengers Madrid Metro March (2002-2007)
Line N. 10 (dark blue) (Adjusted to first business-day of the month)



If we make a general analysis of the rest of Metro lines, we can conclude that all lines followed a similar path, that is, a significant drop in the number of passengers the day of the attack, followed by a sharp increase on 3/12 due to the demonstration (that more than compensates the former). It should be noted, that certain lines (6, 7, 8 and 10) benefited less from this fact.

Finally, it might be worth making a comparison with the Tokyo experience after the sarin gas attacks. According to the study done by our counterpart from LSE (pp. 13-14), Japanese people did not avoid taking underground trains after the sarin gas attacks (although it might be possible that passengers without season tickets might have been influenced in their choice of transport) due to the attacks because of the following reasons:

- Firstly, there is no alternative means of transportation to their destinations, as buses have much lower frequency than the underground and often Delay.
- People in Tokyo do not usually commute or move by their own cars because it takes much longer time than undergrounds and there are not so many parking areas in Tokyo
- The number of death by the sarin gas attacks is five, which is a much smaller number than that of 9/11 or that of the train bombings in Madrid (and also in comparison with the 6,000 victims of the earthquake in Kobe two months before).
- Two days after the attacks some leading members of Omshinrikyo, the offenders of the terrorism, were arrested. Due to the quick arrest and the

confessions, information about the sarin gas attacks could be spread to the public in a short time (p. 15).

In the case of the Madrid bombings we might conclude that the first two points do apply in exactly the same way. But to these we have to sum other aspects: it is true that the impact of the attacks were much smaller than those of 9/11, nevertheless, it was by far the largest terrorist attack in the history of Spain, and thus it seems reasonable, that Spaniards did not compare it primarily to 9/11 but to previous attacks by ETA.

Additionally, the fact that the Spanish Government called for a huge demonstration in repulse of the attack, had implied that the day after the attacks the number of Metro passengers rushed up. Anyhow, the week after the attacks lines 1, 2, 3, 5, and 10 (those lines closer to the place of the bombings) still showed a number of passengers slightly below average (regarding to the two previous weeks) on the week after the attacks. Nevertheless, it seems unlikely that this is exclusively due to a risk avoidance of the Madrilenians.

Trains

Unfortunately we have so far not been able to obtain from the Railway authorities data about the number of train passengers disaggregated on a daily level. Thus we have to relay on the results obtained by López-Rousseau (2005:427), according to which train travel decreased after 3/11 around 4 percent in March and around 6 percent in April (against an average increase of 1% for the 12 months preceding the bombings). Additionally, the railway operators ("Efectos del 11-M") reported significant losses both in the number of travellers and revenues in March and April 2004 (around 9 percent less revenue in the case of long distance trains).

Anyhow, this point might be worth a few comments. López-Rousseau has used in his research the data for the long-distance trains (which are a matter of the Ministry of Transport), although the attacks took place against short-distance trains (which depend from the Comunidad de Madrid, the regional government). As it seemed quite clear that the terrorist were operating on a local area, a look at the data for the short-distance trains might be revealing, also because there are little alternatives to long distance-trains in Spain (except car driving and, in some cases, planes). It might be noted, that the same terrorist cell that perpetrated the Madrid bombings, also tried to explode a bomb on the railways of the (long-distance) train Madrid-Seville on Abril, 2nd. Nevertheless, they acted again locally, as the bomb was deposited only 20 km away of the Madrid. This might have hypothetically altered consumer behaviour regarding the use of long distance trains, but it seems improbable, as they day after (Abril, 3rd) the whole cell was detected in a flat in the town of *Leganés*, where all seven of them committed suicide. Consequently, consumers might have not expected that new attacks should occur.

As told before, we have so far not been able to obtain the daily data for the short-distance trains, but I was permitted access to the data and talked about them with the responsible authorities. The fact is that short-distance trains experienced a significant descent in their number of passenger, which only recovered slowly and did not reach pre 3/11 levels until September 2004. This is interesting, as by then the suicide of the terrorists had diminished the probability of a new attack (police investigations showed that there was no other Islamic terrorist cell operating in Spain in that moment).

The other point that might be commented, is the reduction in the revenue by RENFE (the railway company). According to their own data, these might have even been higher during the first four months of the year, but a closer look reveals that this was mainly due to other factors not related to the bombings.

Cars

Again with have to refer to the study by López-Rousseau (2005:427). Relying on data provided by the Spanish Highway Authorities, highway traffic did not increase after 3/11, but in fact decreased (around 1 percent in March and 3% in April, while the previous twelve months presented an average reduction of 1 percent). Also, fatal accidents on highways decreased after 3/11, thus showing that Gigerenzer's (2004) test of Myer's (2001) hypothesis did not prove true in the case of the Madrid bombings.

Figure 15: Average interannual variation in the number of train travellers, highway vehicles and fatal highway accidents in March and April 1999 through 2003 versus March and April 2004 in Spain (López-Rousseau, 2005:428)

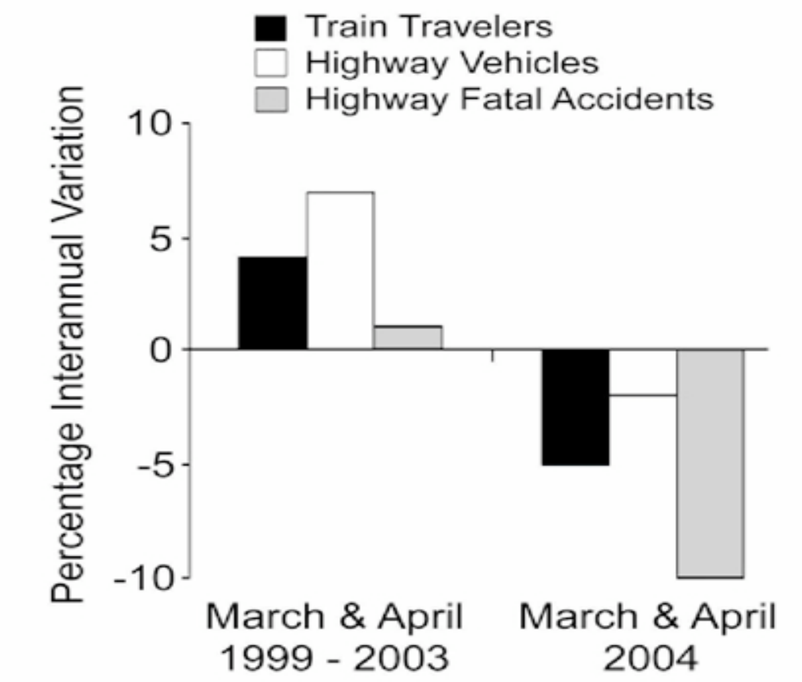


Fig. 1. Average interannual variation in the number of train travelers, highway vehicles, and fatal highway accidents in March and April 1999 through 2003 versus March and April 2004 in Spain.

Finally, it might be commented, that it would be desirable to repeat the analysis considering not the highway traffic, but the possible alterations of the intra-urban use of cars as a response to 3/11. Unfortunately, it has not been possible to obtain that information.

Conclusions

In this paper we have studied in which way the bombings of 3/11 altered Madrilenians consume habits towards public transportation modes. Starting from the fact that López-Rousseau (2005) had already shown that Gigerenzer's (2004) "Dread risk hypothesis could not be verified in the Spanish case, we have analyzed the impact the attack had on the number of Bus and Metro passengers.

So far, our study shows that the attacks indeed altered the consumer's behaviour regarding public transportation modes as a result of the attacks. But this impact, although significant, proved to have a very short term duration.

López-Rousseau (2005:427-428) points out three reasons which may explain why the Madrid bombings —and terrorist attacks in general— may represent less of a dread risk for Spaniards than, e.g. for US-citizens after 9/11:

- 3/11 probably had a smaller psychological impact than 9/11, which had 10 times as many fatalities.
- There is less of a car culture in Spain than in the United States.
- Decades of terrorism in Spain may explain shorter and less intense alarm reactions in Spaniards than in Americans.

Generally speaking we believe this reasons are true. But it should be stressed, that, apart from the magnitude of an terrorist attack., another factor that determines the psychological impact is the novelty ("unprecedence") of the attack mode. Thus, in the case of Spain it might be determinant, that ETA had tried a very similar form of train bombings three months before 3/11. Consequently, it might be relevant for future studies to analyze to which degree that first had already modified consumer's behaviour.

Our results do not contradict the results of the London study. The greater and more significant impact of 7/7 (although not of 7/21) might be easily explained by the fact that in this case the underground lines were directly damaged.

Additionally, it seems clear that consumers de not necessarily extend their risk perceptions symmetrically to all (alternative) transportation modes. Thus, in the Madrid case the attacks against interurban transportation modes affected mainly short distance trains, and only to a less extend Bus and Metro.

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Appendix I: Madrid Metro Train Rout Map

The bombings happened in the Atocha-RENFE Station (light-blue line, n. 1)

Analysis of passengers' reactions to the sarin gas attacks in Tokyo

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Executive Summary

As the decision scientist Gigerenzer (2004) points out, "informing the public about psychological research concerning dread risks could possibly save lives." His research shows that following the September 11th 2001 terrorism a significant number of American residents switched transportation mode, preferring to drive rather than fly. As a result, the number of road fatalities increased by an estimated 1,500 (Gigerenzer, 2004), around 50 percent of the deaths resulting from the initial attacks. Further survey data (Schlenger et al, 2002; Schuster et al, 2001; Silver et al, 2002) adds weight to the argument that these additional deaths resulted from the fear of subsequent terrorist attacks using airplanes. On the other hand, López-Rousseau (2005) states that after the train bombing on March 11th 2004, while Spanish residents also shifted away from the impacted transportation mode, this did not lead to increase of fatal accidents as occurred in the US. This suggests that different contexts produce distinct results, and that public information should be case sensitive. So, in order to build a comprehensive image of public transportation choices in response to terrorist incidents, it is important that numerous cases are investigated and compared with each other.

In this project, the case of public response to the Sarin gas attacks on the Tokyo subway on March 20th 1995 is investigated. It is revealed that unlike the US case or the Spain case, Tokyo residents did not seem to take the action for avoiding the "dread risk" of terror attacks. In other words, the volume of passengers on Tokyo trains after the terrorism did not seem to be influenced by the Sarin gas attacks. Data limitations are a concern here, if we assume the findings are correct, there are numerous reasons for the lack of reduction in passenger numbers. First, Tokyo residents face unattractive substitute options. Underground trains in Tokyo operate frequent, reliable and quick services, while buses and automobiles are hampered by heavy traffic congestion (Cox, 2008). Second, the lack of physical damage to infrastructure, when compared to the Madrid bombings, meant that service could resume quickly. Third, the 5 deaths resulting from the Sarin gas attacks is a significantly smaller number than that of the US and Madrid terrorist incidents. It is also much smaller than the number of deaths caused by the earthquake in Kobe, Japan, two months before.

Introduction

The September 11th 2001 terrorist attacks in the United States shook the world. Along with the incidents since, such as the Madrid train bombing on March 11th 2004 and the subway and bus bombings July 2005 in London, terrorists have targeted civilians traveling on transportation systems. In each case, terrorism appears to have influenced behavior of people living and working nearby. Indeed the literature suggests that individuals avoid the "dread risk" of traveling by the targeted transport mode. Though this may appear sensible, decision scientists point out that the behavior of people according to instinct or feeling does not necessarily reduce risk. If the attacked transport mode carries low risk, then switching to another mode could expose the individual to a greater probability of personal injury or death. For example, following the September 11th 2001 attacks in the US, many individuals switched to driving, and during this period a significant increase in road fatalities was experienced (Gigerenzer, 2004). Therefore research into the calculable risks of transportation modes can play an important role in informing the public response to terrorist incidents. That said, each terrorist attack might elicit a specific public response. For instance, López-Rousseau (2005) suggests that following the train bombing on the March 11th 2004, some Spanish residents switched transportation mode away from the train, yet this did not lead to increase in fatalities. Therefore further study into the public responses to other terrorist attacks on public transportation systems is warranted.

In this project the Sarin gas attacks on the Tokyo subway on March 20th 1995 are investigated. Like the London July 2005 bombings, multiple agents conducted the attacks simultaneously. And like the Madrid and US incidents, the attacks occurred on a single transport mode. Yet it is also a unique case for a number of reasons. First, this is a rare example of the use of chemical agents during an attack, unlike the majority of attacks on public transportation in which bombs are used. Second, the attacks occurred in Japan, carrying with it particular culturally defined, and non-occidental responses. And third, unlike other recent examples, Islamic extremists did not conduct the attacks. Before discussing this case in more depth, a literature review of studies on the passengers' reactions to the terrorism in N.Y. and Madrid is presented. Then the passengers' reactions to the Tokyo attack will be investigated on the basis of Japanese government transportation statistics. Finally the results will be compared with the past studies.

Literature review: US and Madrid terrorist attacks

A number of studies focus on public responses to the September 11th 2001 attacks on the US. Numerous psychological surveys, for example Schlenger et al (2002), Schuster et al (2001) and Silver et al (2002) all provide evidence to suggest that individuals were less likely to travel by air following the attack because of the fear associated with it. These findings are reflected in studies of transportation mode choices. In particular, Gigerenzer (2004, 2006) analyses the impact to the passengers' behavior due to September 11 attacks. Here he sets three hypotheses:

(1) "Americans reduced their air travel after the attack,"
(2) "for a period of one year following the attacks, interstate highway travel

increased, suggesting that a proportion of those who did not fly instead drove to their destination,"
(3) "for the same period, in each month the number of fatal highway crashes. exceeded the base line of the pervious years".

First Gigerenzer shows the data about reduction of air travel in the following year after the attacks. Next he shows indirect evidence for the second hypothesis, which consists of the three facts; "a sudden increase in the individual monthly miles traveled in the months of following the attack compared to the monthly miles of the previous year," "this increase must not be observed in the months before the attack," and "the increase must fade away at some point" (Gigerenzer, 2004). Finally he estimates the total crashes increased by 1,505 deaths after September 11. According to his analysis, after September 11th, Americans avoided taking airplane in order to decrease the possibility of being involved in terrorism yet the increase of cars on highways resulted in more fatal crashes than before the attacks.

López-Rousseau (2005) investigates the train bombing on March 11th 2004 in Madrid, Spain, replicating Gigerenzer's hypothesis tests about the terrorism. He studies the passenger numbers for the impacted mode, the train, and compares these with alternative mode data, and accident and fatality data. He finds that Spanish residents' responses were similar to their American counterparts following September 11th in that train passenger numbers decreased. Based upon this evidence, López-Rousseau (2005) suggests that "avoiding a dread risk is a universal effect" from Gigerenzer's first hypothesis test. In contrast, for Gigerenzer's second hypothesis, the number of cars did not increase, which implies that the third hypothesis was falsified also. López-Rousseau (2005) suggests that Spaniards may have substituted their train travel with carpooling, riding buses, or staying home. The different results of the second and the third hypotheses tests from those in the US case, are attributed to possible psychological and cultural reasons, including the facts that the number of Madrid fatalities is significantly lower, around 10 percent of the September 11th deaths, there is more of a car culture in US than in Madrid, and Spanish residents' greater exposure to terrorism.

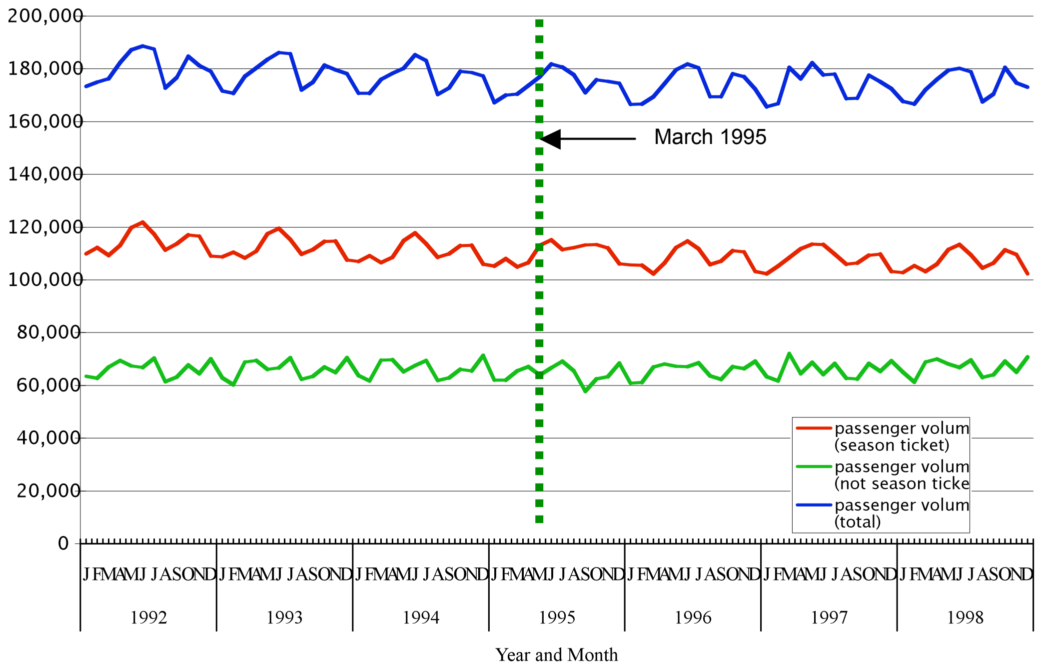
Passengers' reactions to the Sarin gas attacks in Tokyo

At around 8am on March 20th 1995, Sarin gas was released simultaneously onto five "Teito Rapid Transit Authority" (TRTA, a subway system) trains on separate lines near Kasumigaseki station, an area where most Japanese central government agencies are located, including the Diet Building and the Diet Members' Office Buildings. The perpetrators concealed plastic bags containing the toxic nerve gas in newspapers before puncturing them with umbrella tips (Olson, 1999). As a result, 12 people died and 5,510 were injured. The offenders of the terrorism attacks were quickly identified as members of Aum Shinrikyo, although no formal arrests were made specifically for the attacks until some time later due to the requirements of the Japanese legal system.

In this section, we explore the impact of the sarin gas attacks on the volume of passengers of Tokyo's subway system, the "Teito Rapid Transit Authority" (TRTA). Data is obtained from the "Monthly Statistical Report on Railway Transport" published by the Japanese Ministry of Transport. To put this data in a little context, the TRTA rail network covers the Tokyo Metropolitan Area, which has a population of 11.3 million during the day and 8.4 million at night time; a net inflow of 2.9 million passengers each day. In 1995, within the Tokyo central "KU" Area, over 12 billion trips were taken across all transport modes, with over 33 million trips taken on the average day (JSY, 2008). Some 11.5 percent of these journeys were taken on the subway, equating to around 7.2 million journeys on the average day, of which the TRTA comprised the around 80 percent or 5.7 million journeys (JSY, 2008, MSR, 2008). In 1995, TRTA operated eight underground lines in the Tokyo Metropolitan area, including the Marunouchi-line, Hibiya-line and Chiyoda-line, on which the sarin gas attacks were conducted. The rout map is attached as Appendix B although the map is not made in 1995, but is revised in 2008.[25]

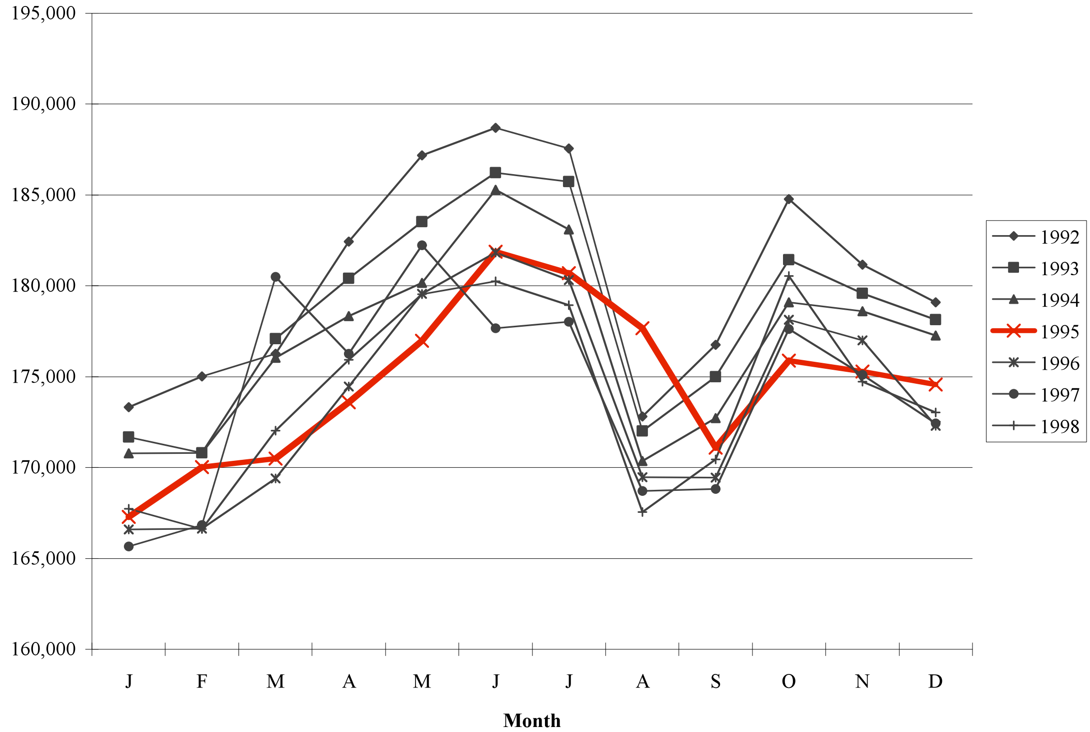
In order to analyze the passenger's reactions to the sarin gas attacks, the change in aggregate TRTA monthly data of passengers' volume from 1990 to 1998 are examined. The data consist of three categories; "passengers with season tickets," "passengers without season tickets," and "total passengers." The time series of these data from 1992 to 1998, the 7 years surrounding the attacks, is shown in figure 1. Here periodic change can be observed, not drastic change before and after the sarin gas attack (March 1995). This is confirmed in figure 2, which shows the yearly change of each data category, and by which the impact of passengers' volume due to the attacks can be more easily checked. In each category, the passenger's volume increases gradually from the beginning of the year to June, drops rapidly in August, and gradually increases again through until October. The 1995 data does not appear to diverge from this annual pattern.

Figure 1: Time series of monthly passenger volume, 1992 to 1998



[25] TRTA was transformed into Tokyo Metro Co., Ltd. in 2004 and Tokyo Metro began to run a ninth line, Fukutoshin line, in June 2008.

Figure 2: Monthly change in total passengers, 1992 to 1998 ('000s)



To explore this further, we perform a univariate time series regression analysis of the TRTA monthly passenger data between 1992 and 1998. In constructing the models, we first use the Dickey-Fuller test to determine that each cut of the data is stationary, and therefore that autoregressive moving average is sufficient to model the process of total (ARIMA [2,0,1]), season tickets (ARIMA [1,0,1]), and non-season tickets (ARIMA [1,0,1]). In each of these models, a seasonal component is included to incorporate the impact of regular annual fluctuations in passenger numbers, which are apparent in figure 1 above. These models produce predicted values following the attack, which have a relatively high degree of predictive capability; when compared to the observed values, our predictions have R-squared values of 0.7136 (Total passengers), 0.7593 (Season tickets), and 0.6231 (Non-season tickets). Unfortunately, as highlighted in Chatfield (1993) and Snyder et al (2001), calculating prediction errors for ARIMA models is problematic for a number of reasons. Here, we provide a sense of the confidence intervals through the residual errors, as shown in figure 5.

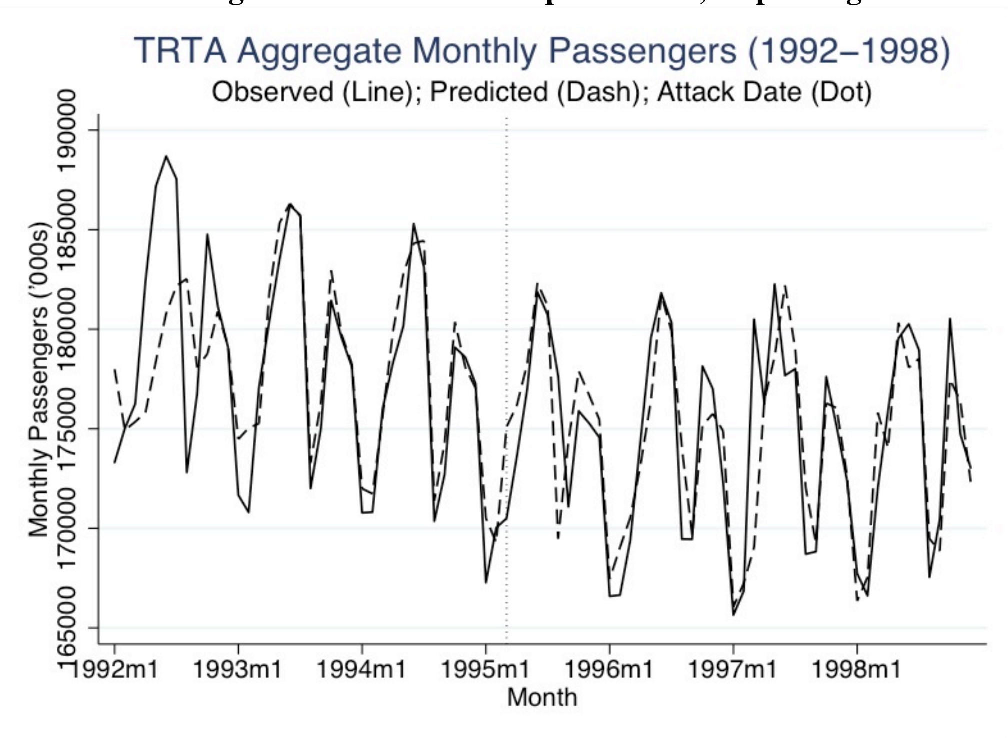
The data in table 1 and figure 5 suggests there may have been a small reduction in passenger numbers following the attacks – some 4.37 million fewer passengers, 2.5 percent of the predicted value. However, we do not believe this is sufficient evidence to rule out the alternative hypothesis that there was no change in passenger numbers following the attacks. The predicted change for all passengers is only 0.6 percent lower than that experienced in January, two months prior to the attacks. Further, as shown in figure 6, although the prediction error (the observed value minus the predicted value) for March 1995 is outside the 99 percent confidence intervals for all prediction errors in the model, it is not sufficiently distinct from errors in other periods, especially in terms of absolute value (which is not shown explicitly in figure 6).

Table 1: Predicted change in TRTA passenger numbers 1995, January-June

Month	All passengers		Season tickets		Non-season ticket	
	Predicted Change	As % of predicted	Predicted Change	As % of predicted	Predicted Change	As % of predicted
January	-3,230,000	-1.9%	-643,000	-0.6%	-2,410,000	-3.7%
February	738,000	0.4%	4,000	0.0%	-365,000	-0.6%
March	-4,370,000	-2.5%	-1,620,000	-1.5%	-3,497,000	-5.1%
April	-3,820,000	-2.2%	-2,139,000	-2.0%	-1,675,000	-2.4%
May	-2,569,000	-1.4%	-1,093,000	-1.0%	-1,763,000	-2.7%
June	-1,552,000	-0.8%	-1,484,000	-1.3%	-343,000	-0.5%

NB – The sum of "Season-tickets" and "Non-season tickets" does not equal "All passengers" as data for each category is produced from distinct predictive models.

Figure 5: ARIMA model predictions, all passengers



According to the result of our time series analysis analysis, the first condition of the Gigerenzer's test is not met; that is, we do not have the sufficient evidence to suggest that Tokyo residents avoided taking underground trains after the sarin gas attacks. Thus Tokyo appears to be a unique case in terms of behavioral response to terrorist attacks on transportation systems. This contradicts López-Rousseau's (2005: 427) statement that "avoiding a dread risk is a universal effect" whereby individuals avoid the attacked mode of transport. The following section explores possible reasons for this unique case, as well as some mitigating circumstances.

A first reason for no reductions in passenger numbers following the attacks is that Tokyo residents have limited transportation substitutes, particularly those modes with greater security against gas attacks. Automobiles and taxis would be one option, yet in 1995 these only accounted for 21.5 percent of all journeys within the "KU" area, the former municipality of Tokyo (JSY, 2008). Moreover, heavy congestion makes these modes a third slower on average than public transport trips (Cox, 2008). Another option would be walking or cycling, both of which are popular in Tokyo. However, the metropolitan area covers more than 2,000 square miles, precluding most commuters from using these modes entirely. It could be argued that individuals may wish to switch from the TRTA to other public transport modes. However, the inflexible nature of the system may make this infeasible for many commuters. Though the TRTA only accounted for around 20 percent of all journeys within the KU area, it is the central part of an integrated network that in 1995 transported over 65 million passengers on the average day. Commuter rail lines, which accounted for 51.8 percent of 1995 journeys within the KU area, feed into the Tokyo subway system, both of which are interconnected further by buses, some 5.3 percent of 1995 journeys. As a result, there are many journeys that could not avoid the TRTA. The final option is to not travel at all, yet this carries with it potentially harmful economic costs.

A second reason is that the relatively low number of deaths resulting from the sarin gas attacks. Although over 5000 were injured, 12 deaths is far lower than the 3,000 that died in September 11th or the 191 that died in the train bombing in Madrid. Moreover, all these figures pale when compared to the 6,000 plus deaths that resulted from the substantial earthquake that hit Kobe, Japan two months earlier. A third reason is that the system was closed only for the day of the attacks. Unlike bombs, gas does not damage the physical infrastructure of the system, and reconstruction is not necessary. There could also be cultural factors as to why Tokyo residents respond differently to Spain and US residents. However, such comparative cultural study does not appear to have been undertaken as yet.

On the other hand, there are some reasons why passengers would be justified in avoiding traveling on the TRTA. First, the government response to the attacks appears to have been hampered. Though the emergency response appears to have been more efficient than that following the Kobe earthquake (Soh, 1995), both the media and government called for improvements (Economist, 1995; Hills, 1995; Howard, 1995). Moreover, the government was slow to identify and apprehend the culprits. Aum Shinrikyo did not accept responsibility for the attacks until 1999 (DPA, 1999), and at the time accused other groups of political conspiracy (KNS, 1995). Partly due to the strict evidence requirements of the Japanese legal system, leaders of the group such as Shoko Asahara were not arrested until May 1995 (Kristof, 1995), and most were not tried until years later. Compounding these issues, further incidents took place in the aftermat, such as letter bomb exploding in the office of Tokyo's governor (Kristof, 1995), and a "mystery gas" engulfing a Yokohama subway station in April (Butcher, 1995).

Second, this was a new type of attack. Terrorism incidents, especially random attacks on civilians rather than government, are uncommon in Japan (Economist, 1995). Indeed, this is a reason that López-Rousseau suggests separates US and Spain residents in their responses to the respective attacks. Also unique was the use of chemical agents for terrorism. Aum Shinrikyo had conducted a sarin attack the year before in Matsumoto, Japan, killing 7 and injuring 200. Yet this was the first terrorist use of chemical gas and there have been limited such incidents since. These points make the lack of a clear reduction in passenger numbers following the attacks somewhat counterintuitive. There are also general data limitations with our study that mitigate the strength of our findings. Our use of aggregate monthly data reduces precision, though it is not possible to acquire daily or weekly passenger data, nor separate line or station data.

Conclusion

We study the March 20th 1995 subway attacks in Tokyo, Japan and compare subsequent passenger behavior with the September 11th 2001 attack on US airlines and the March 11th 2004 train bombing in Madrid. Monthly passenger data for TRTA, the Tokyo subway system, are analyzed through graphical and univariate time series methods. In contrast to López-Rousseau (2005), who states, "avoiding a dread risk is a universal effect," our study finds that Tokyo residents did not avoid taking the subway following the terrorist attacks. They appear not to have reacted in the same way as residents as residents of the US or Spain. This paper suggests there a number of reasons for this. First, transportation substitutes are limited. Second, the number of deaths is lower than the US and Madrid terrorist attacks, as well as the Kobe, Japan earthquake in early 1995. Third, the subway system was closed for only the day of the attack. That government response to the attacks was hampered, and these were new to the Japanese, makes these results somewhat counterintuitive.

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Appendix:

Figure A1: Monthly change in Season ticket passengers, 1992 to 1998 ('000s)

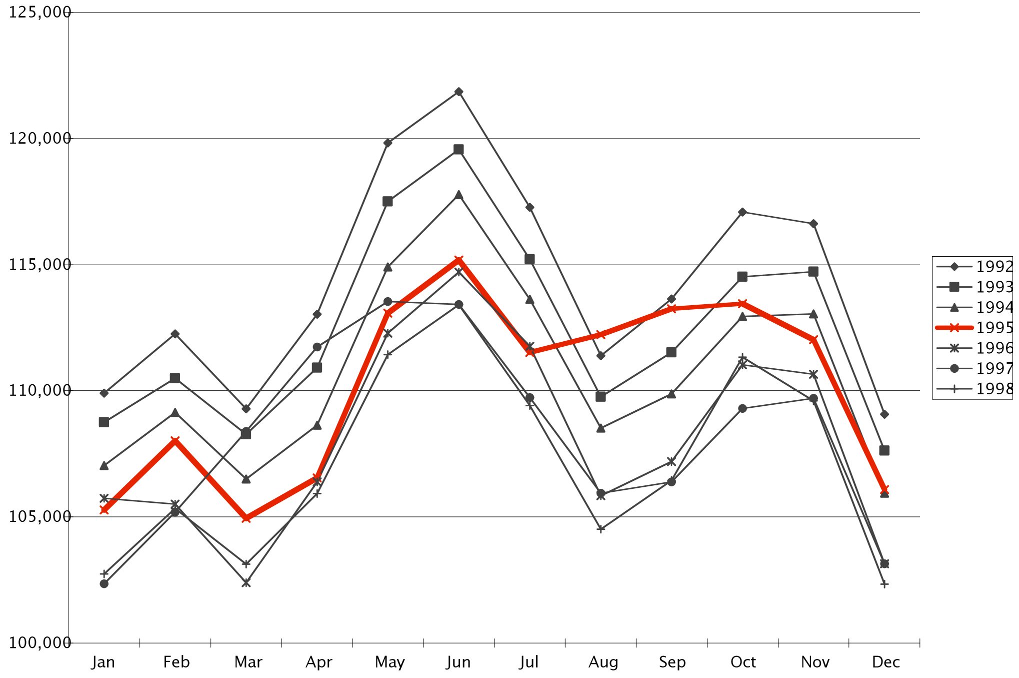

Figure A2: Non-season ticket passengers ('000s)

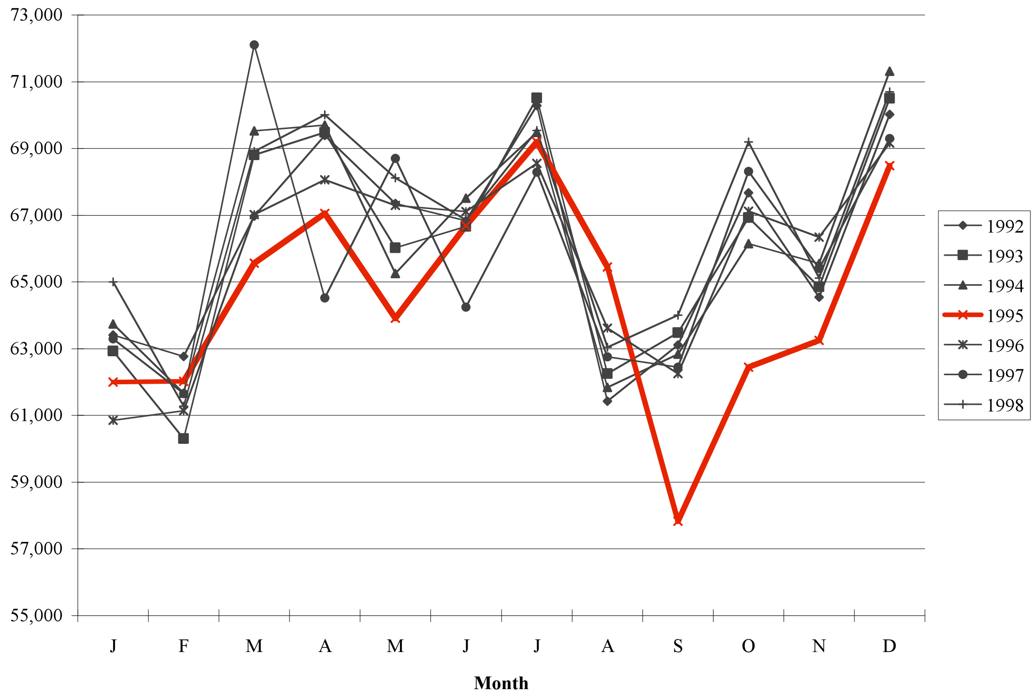

Figure A3: ARIMA model predictions, season tickets

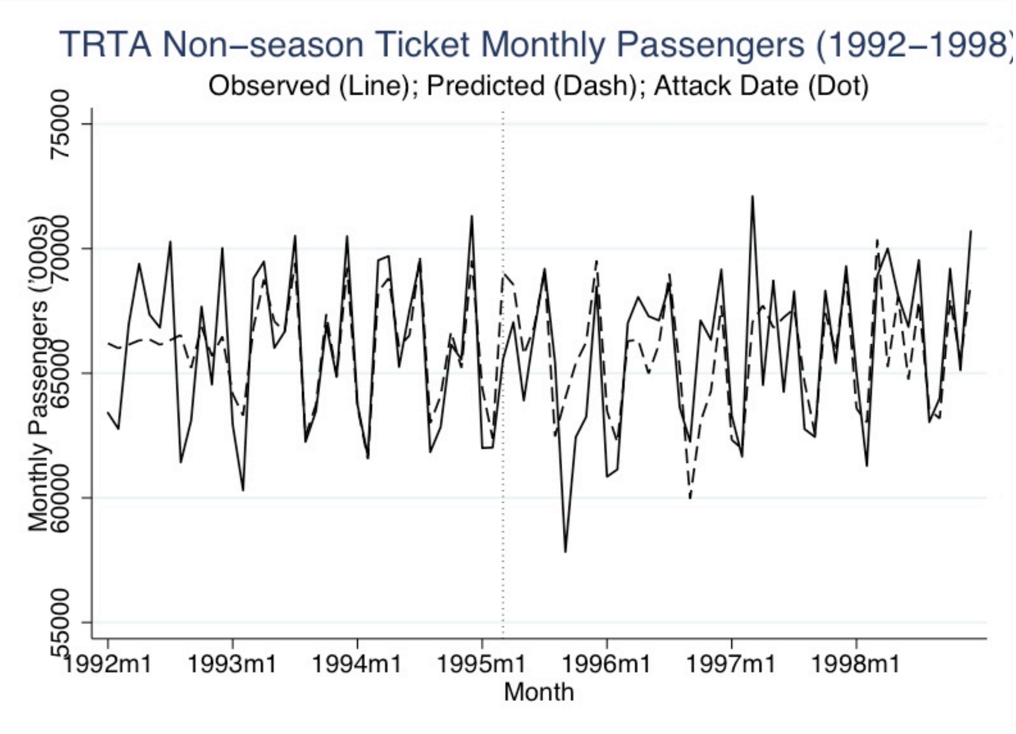

Figure A4: ARIMA model predictions, non-season tickets

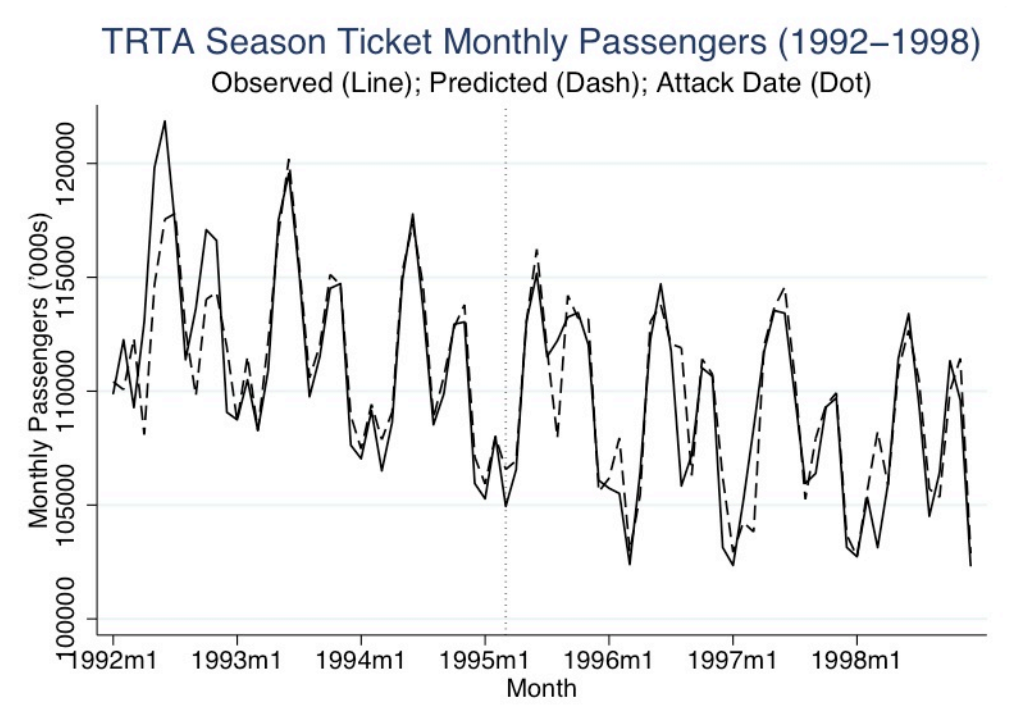

Figure A5: ARIMA model prediction errors, season tickets

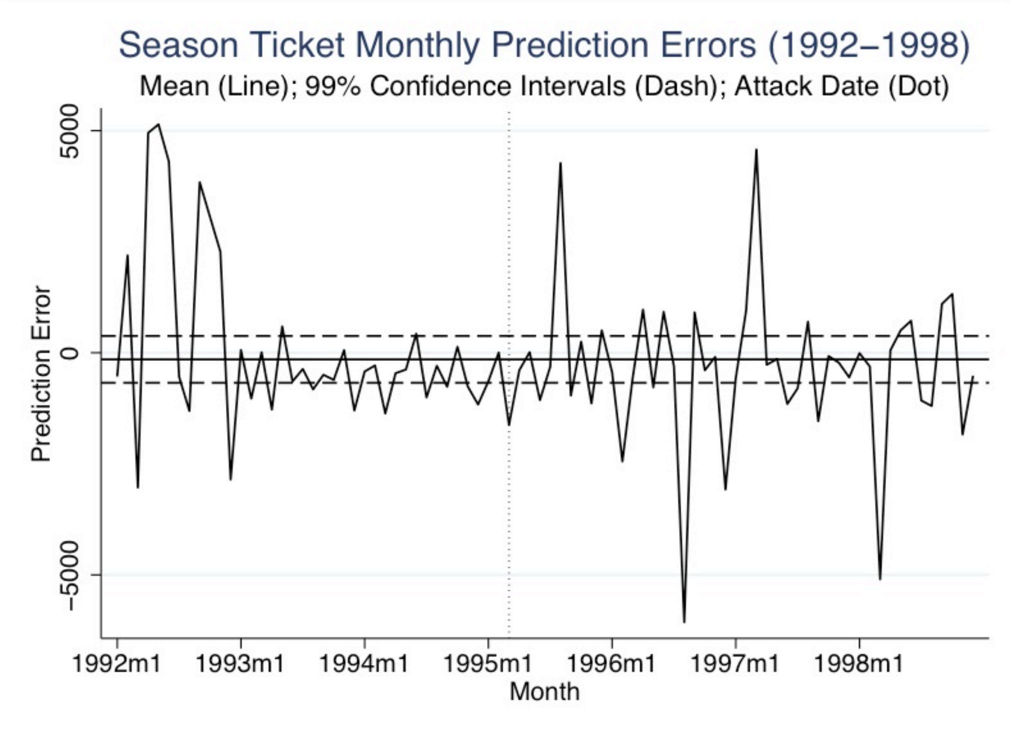

Figure A6: ARIMA model prediction errors, non-season tickets