Roads and the diffusion of insurgent violence

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How does insurgency spread? The persistence, expansion and relocation of military operations are difficult to divorce from the prior history and local context of an armed struggle. While a growing body of disaggregated conflict research has sought to account for the spatial and temporal interdependence of conflict events (Hegre et al., 2009; Lyall, 2009; Raleigh et al., 2010), this dependence is rarely treated as a subject of primary theoretical interest. At present, the observation that violence can spread and contract in endogenous, self-feeding ways is widely acknowledged (Kalyvas, 2008) and is supported by rich empirical evidence (O'Loughlin and Witmer, 2011; Schutte and Weidmann, 2011; Townsley et al., 2008; Weidmann and Ward, 2010), yet we know relatively little about the mechanisms by which this diffusion occurs – the signals that must be transmitted for violence to spread, and the channels by which these signals travel.

This paper offers an initial look at one of the most basic of these mechanisms – logistics, particularly the transportation of personnel and equipment over a road network. The logic of diffusion is guided by a simple epidemic model, in which the spread of insurgency is constrained by the connective topology of the physical space which it affects. The diffusion of insurgency requires: (1) a location currently experiencing insurgent violence, (2) a location susceptible to insurgent violence, and (3) a channel of communication between the two. Where insurgents can easily travel from restive to peaceful locations, and where accessible targets are of high intrinsic value, violence can be highly contagious. As noted by Jomini (1862), "Strategy decides where to act; logistics brings the troops to this point" (p. 69).

Using new disaggregated data on road networks and political unrest in Russia's North Caucasus region, I test several empirical predictions derived from this model, and find that roads shape insurgent target selection and facilitate the physical spread of violence. These findings challenge the conventional view that insurgent logistics are either self-sufficient or highly adaptive. Because the military activity of non-state actors is constrained by existing infrastructure, violence can be most contagious in areas that are logistically best-developed.

This contagion, however, is self-limiting. Although the logistical ease of shifting resources between targets facilitates the diffusion of violence to new locations, the need to allocate limited resources between multiple neighboring contested areas limits the ability to sustain fighting in any one place. At the local level, this dynamic makes the relocation of insurgent activity more likely than its expansion – in contrast to conventional wisdom on the tactics of unconventional warfare (Kalyvas, 2007; Schutte and Weidmann, 2011).

Methodologically, this paper demonstrates that a failure to account for logistical constraints in empirical models of civil war can produce misleading predictions about the scope of conflict diffusion. By under-estimating the costs of travel between locations, traditional geodesic distance overpredicts opportunities for violence to spread. The use of road network data can yield more conservative and, ultimately, more accurate models of civil war.

This paper is structured as follows. I begin with a short overview of applied research on the political geography of insurgency and civil war, and relate it to a simple epidemic model that illustrates the logic of conflict diffusion. I then introduce the region that serves as the empirical focus of this inquiry, Russia's North Caucasus, and outline the data collection strategy and modeling techniques used for the statistical test. Empirical findings are presented, along with a series of simulations under different conceptualization of distance. I show that the paper's findings are robust to statistical tests that directly account for unobserved cross-regional differences and the endogeneity of government responses to insurgency. The paper concludes with a summary of its contributions.

1 The logistics of diffusion

Much contemporary writing on civil war is motivated by the perception that the onset and dynamics of armed conflict are theoretically and analytically distinct: if the former asks how exogenous factors influence the outbreak of conflict, the latter asks how conflict feeds itself. In exploring how violence begets violence, "diffusion" refers to a class of mechanisms by which armed conflict spreads and recedes across space and time (Starr et al., 2008). Initially limited to research on international conflict (Boulding, 1962; Alcock, 1972; Houweling and Siccama, 1985; Siverson and Starr, 1991), diffusion-based explanations have since permeated cross-national studies of civil war (Buhaug and Gleditsch, 2008; Braithwaite, 2010) and, more recently, disaggregated research on the local dynamics of conflict (Weidmann and Ward, 2010; Schutte and Weidmann, 2011). Although the concept can readily apply to emulation, adaptation and similar processes that do not rely on direct physical contact between units, most conflict research has placed geographic proximity at the center of the diffusion story: violence is more likely to "spill over" to nearby locations than to distant ones.

Every story of diffusion rests on often unspecified assumptions about (1) the signal that must be transmitted for violence to spread, and (2) the transmission channel by which the signal is communicated. These signals and channels may be physical (e.g. weapons transported by airlift) or immaterial (e.g. information transmitted by a gossip network). While these assumptions have been explored in depth by scholars of international conflict (see Starr (2005) for a review of this literature), few studies have explicated the logic of geographic diffusion on the local level of civil war. This vagueness stems as much from incomplete theoretical conceptualization as from challenges of empirical measurement.

From a ground-level military perspective, diffusion relates to how operations can be sustained, expanded or relocated to various geographical areas. For irregular insurgent forces and forward-deployed troops alike, this question is usually a logistical one, involving the deployment of a limited pool of personnel, weapons and supplies to areas where they are likely to yield the greatest strategic gains. Military operations feed on a combination of local or prepositioned supplies, captured supplies, and supplies transported from external sources. Not all battlefields are equally accessible from the outside world. A range of geographical barriers – from impassable terrain to extended deployment distances – can limit belligerents' options. By physically connecting locations to one another, roads offer low-cost routes for the local movement of personnel, ammunition, spare parts, food, fuel and other essentials needed to initiate fighting, and to keep it going.

The theoretical and empirical debate on the role of road networks in insurgency and civil war remains divided. A prevailing view among many practitioners and political scientists holds that modern transportation infrastructure is either irrelevant or unnecessary to insurgents. The proposition that insurgent logistics are self-sufficient holds that lightly-equipped guerilla units are less reliant on external sources of supply than on foraging and the support of the local population (Mao, 1961, 111). The proposition that insurgent logistics are highly flexible holds that where external supplies are needed, rebels can draw on a mix of transport means – trails, rivers and even air – as evidenced by the famously adaptive and diverse supply networks of Soviet Partisans (Turbiville, 2005, 29) and the Viet Cong (Holliday and Gurfield, 1968, 47-50). In each case, the ability of insurgents to access the road network is not seen as a major risk factor. If anything, roads may reduce the risk and severity of civil conflict – by multiplying the reach and mobility of government forces and integrating otherwise isolated and at-risk communities into the economic life of a state. This view is found in classical and contemporary literature on counterinsurgency (Campbell, 1968; O'Neill, 1990; Kilcullen, 2008), cross-national studies of civil war (Herbst, 2000; Fearon and Laitin, 2003; Collier and Hoeffler, 2004), as well as some disaggregated civil war research (Murshed and Gates, 2005; Bohara et al., 2006; Buhaug and Rod, 2006; Raleigh, 2007).

A more cautious view insists that insurgent logistics are neither self-sufficient nor boundlessly flexible, but are highly constrained by existing infrastructure. Roads reduce the costs of insurgent operations by facilitating rapid access to and extraction from targets of opportunity, and enabling the rapid delivery of supplies. This view is supported by disaggregated civil war research in a variety of regional settings (Raleigh and Hegre, 2009; O'Loughlin et al., 2010; O'Loughlin and Witmer, 2011), as well as analyses of internal Al Qa'ida documents (Felter and Watts, 2007) and WikiLeaks incident reports (O'Loughlin et al., 2010). This newer literature suggests that organized violence generally – whether government or insurgent, in flat terrain or mountain valleys – is constrained by road networks. Even for lightly-equipped insurgents, locally-supplied goods will likely be limited to food, water and fuel. The flow of fighters, ammunition, and spare parts still requires open supply routes and logistical connections to the outside world.

Despite the centrality of logistics and transportation infrastructure to the geography of political violence, it is surprising that road networks have not been employed to greater effect in the empirical measurement of spatial proximity. Some initial efforts have examined the effects of road density and type in war (Buhaug and Rod, 2006; Raleigh and Hegre, 2009), as well as the proximity of towns to major highways (O'Loughlin and Witmer, 2011; O'Loughlin et al., 2010). While notable exceptions have appeared in related fields, particularly the study of transnational (Lloyd et al., 2011) and urban crime (Lu and Chen, 2007), few, if any, civil war studies have attempted to use path distances from road data to construct spatial weights and model the networks through which the diffusion of violence might take place.

If we accept the premise that opportunities to reinforce an ongoing fight or expand its geographical scope depend on the existence of open communications between localities, conventional measures of geographic distance can be misleading. To account for the mutual accessibility of neighboring areas and their influence on each other, most studies employ spatially lagged measures of how many neighboring areas have recently experienced violence, or how close a unit is to other violent hot spots. Such terms, however, have traditionally been constructed with areal contiguity, Euclidean and geodesic point-to-point distance measures, which do not realistically represent how people and vehicles are likely to travel – particularly in rough terrain where a linear or spherical distance assumes that one is able to walk through a mountain to get from point A to point B.[1] While the inadequacy of the geodesic assumption may seem obvious to counterinsurgency practitioners and casual observers, this assumption is pervasive in political science literature, and has been shown elsewhere to introduce substantial bias into estimates of spatial dependence (Lu and Chen, 2007).

In a sparse and poorly connected transportation system, where numerous turns and circuitous routes are required to access some points, the geodesic distance between two locations will be significantly shorter than actual road distance. As a result, the use of Euclidean or geodesic distance in global measures of spatial autocorrelation can result in false positives, indicating the presence of spatial clusters or "hot spots" where there are none (Lu and Chen, 2007, 619-620, 624). In rural areas with rugged terrain, which have provided the empirical setting for much micro-level civil war and insurgency analysis, this problem is likely to be pervasive.

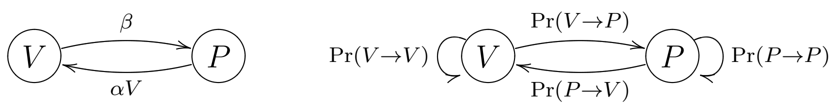
2 The logic of diffusion

To clarify the role of logistics in civil war, a more formal conceptual framework is needed to parse out where opportunities and motivations for violence might emerge, and how roads – conditional on other structural and dynamic factors – may amplify or reduce them. One approach is to model the outbreak and spread of insurgency as an epidemic. The diffusion of insurgent violence requires three conditions: (1) a location currently experiencing violence, (2) a location susceptible to insurgent violence, and (3) a channel of communication between these two localities. The signals to be transmitted between locations are the insurgent personnel, weapons and supplies needed to conduct attacks. Road infrastructure serves as the transmission channel by which these signals travel.

At its most basic level, an epidemic model rests on two parameters: *transmissibility* and

[1] In the current context, geodesic distances are understood as a generalization of Euclidean "straight-line" distances to a curved space, such as the surface of the Earth.

recovery. In a group of peaceful (P) and violent (V) locations, transmissibility governs how easily insurgents can travel from a location of type V to one of type P. This parameter represents the opportunity for violence to spread, with high values suggesting extensive road links between municipalities, and low values indicating a landscape with poorly connected transportation infrastructure. The recovery parameter governs how severe and prolonged a violent spell will be. This captures the intrinsic value of a location, as a function of the local environmental factors and conflict dynamics that inform insurgent target selection. Slow recovery rates indicate that violence is likely to persist once initiated, and fast rates indicate the opposite.



(a) Deterministic (b) Stochastic

Figure 1: **Epidemic Model**

The transition of locations between violent and peaceful states can be formalized in two ways: as a system of ordinary differential equations (ODE) that consider rates of transition in continuous time (Figure 1a), or as a Markov Chain that considers probabilities of transition over discrete intervals of time (Figure 1b). In the first case, transmissibility is expressed by parameter α and recovery by β. If we take P_t and V_t to represent the proportion of villages in each group at time t, then change in the proportion of violent units is increasing in the ease of communication between peaceful and attacked locations (αVP) and decreasing in the ability of targeted villages to withstand and recover from attack (βV):

$$\frac{\delta V}{\delta t} = \alpha V_t P_t - \beta V_t \qquad \frac{\delta P}{\delta t} = -\alpha V_t P_t + \beta V_t \tag{1}$$

With the constraints $P_t + V_t = 1$ and $0 \leq \beta/\alpha \leq 1$, the following time-independent equilibrium solution can be derived:

$$V_{eq} = 1 - \frac{\beta}{\alpha} \qquad P_{eq} = \frac{\beta}{\alpha} \tag{2}$$

where V_{eq} is the probability that a given village will become attacked during the course of an insurgent outbreak, and P_{eq} is the probability that it will remain at peace.

The expressions in (2) yield two central predictions. First, risk of violence is greater if transmissibility (α) is high, and insurgents can easily travel from village to village. Second, risk will increase if recovery (β) is low, indicating that insurgents have a strong attachment to particular targets in the region. In the first case, the overall risk is amplified by opportunities for violence to spread to new locations. In the second case, it is fed by the persistence of violence in already-contested areas. If the road network is poorly connected and available targets offer little strategic gain, villages are more likely to remain at peace.

Although an ODE model can be effective in formalizing the logic of an epidemic, we may wish to use this logic to empirically investigate patterns of insurgent violence, while explicitly accounting for chance and uncertainty. In the stochastic Markov Chain model, deterministic transmissibility and recovery rates are replaced by probabilities of transition from peace to violence [$\Pr(P \to V)$ or $1 - \Pr(P \to P)$] and from violence to peace [$\Pr(V \to P)$ or $1 - \Pr(V \to V)$]. At each time step, a location transitions to a new state, or remain in its current one.[2]

As the state transition diagrams suggest, the determinants of new and recurring acts of violence are not the same. While transmissibility governs the transition of previously peaceful villages to violence, recovery governs whether violent villages will remain in conflict

[2]The rates and probabilities are related. If we assume that the time length a unit spends in each state is exponentially distributed, with rates specific to each state, then the probabilities of new and recurring violence can be expressed as $\Pr(P \to V) = 1 - \exp(-\alpha V)$ and $\Pr(V \to V) = \exp(-\beta)$.

or transition back to peace. This differentiation allows us to apply epidemic logic to several patterns of violence identified in disaggregated literature on the diffusion of crime and civil war (Cohen and Tita, 1999; Schutte and Weidmann, 2011). A system with high transmissibility and slow recovery would likely witness an *expansion* of conflict, as insurgents spread their activity to new locations, while previously affected areas continue to experience fighting. A system with high transmissibility and fast recovery would more likely see a pattern of *relocation*, as insurgents carry the fight to new areas after abandoning old ones. Low transmissibility and slow recovery would produce *hot spots*, where some locations experience a persistent state of violence, but the unrest is contained and does not spread outward. Low transmissibility and fast recovery would suggest *sporadic fighting*, a series of short-lived, non-contagious episodes of violence.

Transmissibility and the opportunity for new violence

Unless all violence unfolds in isolation – a situation in which insurgents are immobile and only conduct attacks in the same towns in which they sleep and eat – the accessibility of potential targets must be taken into account. While roads are not always necessarily for access, they greatly simplify this task, especially in rugged terrain where the set of alternative navigable paths between pairs of locations is limited. If a village is accessible by road, insurgents are able to more easily access targets within it and more quickly extract themselves when security forces respond. Despite their accessibility from centers of government power, towns and villages situated in critical junctions make convenient targets and can become exceedingly difficult to secure (O'Sullivan, 1989, 100). As noted by the U.S. Army's Counterinsurgency Field Manual, multiple avenues of approach to population centers can frustrate efforts to interdict insurgents and control their movements (Headquarters, Department of the Army, 2006, 5.21).

The diffusion of violence, however, is not unconstrained. Insurgent groups tend to recruit locally, and limit their fighting to places in close proximity to the local hub, generally no more than a day's drive away (Arjona and Kalyvas, 2009; Forsberg, 2009; Biddle and Friedman, 2008). If we assume that insurgent power projection is subject to the same sort of distance decay felt by government forces, new acts of violence should be expected at short road distances from recent hotspots of insurgent activity.

A number of static structural factors also shapes opportunities for violence. While rural, sparsely-populated, underdeveloped environmental conditions are often seen as terrain favorable to the establishment of insurgent base camps outside the reach of government forces (Fearon and Laitin 2003, 81, Collier and Hoeffler 2004; Bohara et al. 2006; Kalyvas 2006, Lyall 2009, 342), secluded areas rarely offer a rich set of targets for attack (Buhaug and Lujala, 2005; O'Loughlin and Witmer, 2011). For insurgents who seek to attract public attention and signal their strength, major population centers hold the promise of a large number of physical targets, significant media visibility, the ability to disappear into the population, and – due to the risk of collateral damage – neutralize the government's ability to employ countermeasures like air power, artillery and mortars (Clapham, 1986; Herbst, 2000; Raleigh and Hegre, 2009). For these reasons, insurgents are likely to be drawn to territories with high population density, located in accessible, low-elevation areas.

Recovery and the motivation for continued violence

Although physical access facilitates the diffusion of violence to previously peaceful locations, topological considerations generate many more such opportunities than are actually exploited by insurgents. Given a set of logistical constraints, insurgents are likely to expend their limited human and material resources in a way that maximizes the strategic impact of an attack: by deploying additional assets to an actively contested territory, by undermining the perceived capacity of the local government, by inflaming pre-existing local tensions, or by increasing the visibility of an armed struggle.

An ongoing campaign in a contested zone is likely to draw insurgent resources from proximate areas, either to hold ground and control territory (Biddle and Friedman 2008), to punish or deter defection (Findley and Young 2006; Humphreys and Weinstein 2006, but also see Kalyvas and Kocher 2009), to tie down government forces (O'Neill 1990, 46; Marighella 2002), or to build on prior military accomplishments. Insurgent target selection also reflects an expectation of the government's likely response. A high likelihood of reprisals may deter insurgents from attacking particular targets. Alternatively, insurgents may actually wish to provoke the government into (over)reacting, so as to exploit instances of government repression for recruitment purposes (Bueno de Mesquita and Dickson, 2007).

The strategic pull of contested areas also exposes a self-limiting mechanism in the spread of insurgent violence. The existence of several mutually-accessible battlefronts compels locally-based insurgents to decide how best to allocate their limited resources: continued fighting in location A will typically come at the expense of continued fighting in location B. If the opportunity cost is deemed too high, fighting in both locations will be difficult to sustain. In this context, the structure of a road network will determine whether locations A and B are seen as competitors for the same pool of resources (say, if A and B are just 1 km apart), or as relatively independent theaters of operation (500 km apart). In the first instance, perceived tradeoffs are more likely to inhibit insurgents' ability to sustain both operations. In the second, each fight can conceivably be sustained without compromising the other.

3 A violent epidemic in the North Caucasus?

Russia's North Caucasus offers a suitable testing ground for these arguments. The region is home to a diverse set of structural conditions – from densely populated urban centers to remote mountain outposts, from locations fully integrated into the country's transportation grid to ones virtually inaccessible by a motorized vehicle. Opportunities for violence to relocate, expand or persist have depended greatly on insurgents' ability to transport weapons, personnel, fuel, narcotics, stolen vehicles, and other cargo along often sparse and treacherous lines of communication. 70.9 percent of insurgent attacks between July 2000 and December 2008 occurred in the 40.2 percent of municipalities located within 1 km of a highway, primary or secondary road. This dependence on road networks holds for attacks against both civilian (71.3) and government targets (70.7). Just 3 percent of attacks have occurred more than 5 km from the network.[3]

For much of the conflict's recent history, fears (or hopes) of an epidemic-like spread of violence have shaped strategic planning and public debate among belligerents and observers alike. Insurgent leaders, like the late President of the separatist Chechen Republic of Ichkeria (ChRI) Aslan Maskhadov, openly sought to expand the conflict geographically: "We are capable of carrying out operations in Ichkeria, Ingushetia, and Russia, and we will prove it."[4] Preventing this expansion has been a central component of Russia's military mission, as articulated by then-Prime Minister Vladimir Putin in 1999: "The first phase is a *cordon sanitaire*. [The second] is the total annihilation of the terrorists. How this will be done, and in what timeframe – we will soon learn."[5]

As a conflict launched with the overt aim of preventing the spread of destabilization from Chechnya into neighboring areas of the North Caucasus, the Second Chechen War has in some ways produced the opposite of its intended result (Souleimanov 2007, 301, Kuchins et al. 2011, 3-5). Prior to 1999, Russian military strategy in the region focused on isolating the separatist ChRI, which had enjoyed de facto independence from Moscow since 1996. The

[3]Attack statistics taken from (Memorial, 2009). Full description of dataset provided below.

[4]"Maskhadov, Rossiya i Zapad [Maskhadov, Russia and the West]," *Echo of Moscow* [radio broadcast], 11 March 2005.

[5]"Vladimir Putin otvetil na voprosy zhurnalistov po Chechnye i inostrannym investitsiyam [Vladimir Putin answers journalists' questions on Chechnya and foreign investments]," *Channel One* [television broadcast], 4 October 1999.

cordon sanitaire was breached in early August 1999, when roughly 1,500 armed Chechens, Avars, Dargins and Arab foreign fighters led by the field commanders Shamil Basayev and Ibn al-Khattab, crossed the border into the neighboring autonomous republic of Dagestan, occupied several Salafi villages, and quickly proclaimed an independent Islamic Republic of Dagestan (Souleimanov 2007, 147, Grodnenskiy 2010, 139-146).

With the support of local militia, federal troops quickly pushed the rebels back into Chechnya and launched an offensive aimed at regaining control of low-lying areas north of the Terek and Sundzha Rivers, encircling and capturing the Chechen capital of Grozny, and pushing ChRI forces out of all major population centers. To prevent the movement of insurgent units from mountainous back to low-lying parts of the republic, Russian airborne troops established a system of fortifications, checkpoints and mine fields in the Shali and Urus-Martan districts, severing lines of maneuver and routes for the delivery of weapons and supplies (Grodnenskiy, 2004, 385).

By the spring of 2000, the conventional phase of the war had ended. A provisional pro-Moscow Chechen government was established, and remaining rebel fighters fled to the seclusion of the republic's forested and mountainous south. Having suffered heavy losses in previous months, fractionalized and internally divided ChRI forces abandoned positional battles in favor of guerilla warfare (Kramer 2005, 203, Schaefer 2011, 192-194). The offensive maneuver war that characterized the invasion of Dagestan was replaced by raids, drive-by shootings and targeted assassinations. The active, fortified defenses used against advancing Russian troops were replaced by roadside bombings, mine warfare and ambushes on security checkpoints (Grodnenskiy, 2004, 443). Although larger attacks against population centers continued, their objectives became increasingly to terrorize the population and demonstrate the limits of Russian power, rather than to control and hold territory (Grodnenskiy, 2010, 145, 353-364).

For its part, Russian strategy shifted from an early reliance on overwhelming artillery and air power to more limited cordon-and-search (*zachistka* or "mop-up") operations, in which security forces block a village or town and conduct house-to-house searches, sometimes accompanied by indiscriminate arrests and disappearances (Politkovskaya, 2002, 175). Gradually, Moscow transferred most of these policing duties from regular troops to the Federal Security Service (FSB), regional interior ministries (MVD) and local pro-Moscow militias, producing a mixed record of success (Malashenko and Trenin 2002, 135-137, Kramer 2005; Lyall 2010; O'Loughlin et al. 2011).

This pattern of insurgency and counterinsurgency – the focus of the empirical analysis below – has persisted, in varying degrees of intensity, from mid-2000 to the present day. The geographic spread of the fighting, however, has been gradually expanding (O'Loughlin and Witmer, 2011, 191-93). The goal of "broadening the front of military resistance" within and beyond the borders of Chechnya was first articulated by Maskhadov in 2004, and was actively pursued by his successors Abdul-Khalim Sadulayev and Doku Umarov, who worked to establish operational ties with local Salafi *dzhamaat*s in every other North Caucasus republic (Hahn 2006, 559, Hahn 2008, 17-18). Although this strategic intent was often overtaken by the momentum of local conflict dynamics, instability gradually engulfed the entire region – by 2007 recorded levels of violence in Chechnya were matched or exceeded by those in neighboring Ingushetia and Dagestan (Kuchins et al., 2011, 3-4).

Although the strategic rationale behind spreading insurgent activity – broaden the base of support and divert Russian military resources (Souleimanov, 2007, 287-289) – is well-documented, physical opportunities for violence to spread have received considerably less attention. In the present conflict, as in previous ones, logistics lie at the heart of diffusion story. Chechnya is positioned at the center of a vast regional network of roads, railways and oil pipelines. Historically, this infrastructure was designed to keep the republic's various municipalities connected to each other, and the wider Caucasus region economically integrated with the rest of the country (Vendina et al., 2007, 186). Its origins lie in the 19th Century Caucasus Wars, when the Russian Army sought to overcome the tyranny of geography through massive deforestation, road construction and forcible resettlement of mountain communities to low-lying areas more proximate to Russian centers of trade and administration (Gordin 2000, 270, Degoyev 2000, 150). Even in this early period, however, insurgents were quick to adapt. Imam Shamil routinely used the newly-constructed roads to conduct incursions and reconquer contested areas recently brought under Russian occupation. In response to a series of such raids in 1849 on the villages of Galasha and Karabulak in modern-day Ingushetia, the local commander, General-Major Nikolay Sleptsov, reversed the construction policy and sought to prevent the infiltration of "nonpeaceful highlanders" (*nemirnye gortsy*) by making road links to Shamil's territory impassable (Gammer, 1998, 252).

Similar challenges have confronted Russian forces during the most recent period of instability. General-Colonel Gennady Troshev, former commander of the North Caucasus Military District, has cited the importance of roads to the strategy of Basayev's guerillas in the early stages of the Second Chechen War: "[the insurgents] would enter neighboring villages, disarm the police and establish their own government ... villages where they were active would need to be blocked [and] all roads would have to be mined ... to cut off their exit routes and prevent supplies and reinforcements from reaching them" (Troshev, 2001, 17). Government efforts to block the roads were often met with fierce resistance, particularly where they obstructed important caravan routes (Grodnenskiy, 2004, 453). One such incident in the vicinity of Prigorodnoye and Gikalovskiy resulted in a three-day battle to re-open a transportation corridor to Shali (Troshev, 2001, 19). Even well-defended choke points like the "Caucasus 1" border crossing between Ingushetia and Chechnya became sites of daring attacks by rebels seeking to transport weapons, explosives and other supplies in and out of the conflict zone (Rechkalov, 2003).

The insurgents' reliance on road mobility led to a number of tactical innovations, as illustrated by captured insurgent documents: "Particularly effective are operations on mobile weapon platforms. Vehicles like 'UAZ', Jeeps and other light trucks are mounted with mortars, machine guns, anti-tank guns and rocket-propelled grenades. [...] Attacks are carried out from temporary fire positions (5-6 shots), and the location quickly changes" (Kirilenko, 2000). The lifting of roadblocks was typically followed by a surge of rebel activity. When the republic's Head of Administration Akhmat Kadyrov cut in half the number of checkpoints in late 2001, federal forces began taking heavy losses around strategically-positioned hubs like Shali and Argun, where roadblocks had previously been concentrated (Grodnenskiy 2004, 463).

Roads have been no less relevant to insurgent groups elsewhere in the region. The Caucasus Federal Highway (M-29) – which extends through nearly every major city from Pavlovskaya in Krasnodar Kray to Magaramkent in southern Dagestan – has been a regular site of improvised explosive device (IED) attacks against police, local administration and civilian targets (Lyall 2006, O'Loughlin and Witmer 2011, 186, O'Loughlin et al. 2011, 44-45). Local roads have been no less dangerous. Drive-by shootings – mostly against law enforcement officials – have been among the most frequent and efficient modes of attack employed in the low-level street wars in Ingushetia and Dagestan. Most of these incidents take place at gas stations, private residences and business parks near city outskirts, where perpetrators from outside can rapidly access their targets and escape pursuit by driving across town and district lines (Ware and Kisriev, 2010, 185-188).

A reliance on automobile traffic can be observed in the strategy and tactics of almost every insurgent group in the North Caucasus – from nationalist militias in Chechnya to Salafi-Jihadist *dzhamaats* in Dagestan, Ingushetia and Kabardino-Balkaria. International efforts to interdict terrorist finances and electronic communications have only increased insurgents' reliance on couriers and traditional logistics (Hahn, 2008, 14-15). The distribution of roads and accessible targets, however, is far from uniform across this territory. In contrast with the relatively developed infrastructure of Chechnya, much of Dagestan is fragmented into mountain enclaves, sparsely connected by narrow valleys (Reynolds, 2005, 35). Rather than enabling interactions between localities, this terrain "complicates communications and forces roads to follow ceaselessly winding paths, negotiating steep descents and climbs" (Gammer, 1998, 29). In the words of Soviet geographer Nikolay Gvozdetskiy, "the devil himself should be minister of transportation in Dagestan."[6] The question then turns to how these differential opportunities to exploit the road network shape the manner in which violence can spread.

4 Data and methodology

To explore patterns of diffusion empirically I use new disaggregated data on violent incidents in the Russian North Caucasus. The panel dataset is based on monthly observations across 4,033 municipalities in the seven autonomous republics of the North Caucasus.[7] The sample of villages and towns is universal, encompassing all populated places within these republics, as listed in the National Geospatial-Intelligence Agency's GEOnet Names Server (GNS). The time frame – July 2000 through December 2008 – excludes the initial conventional phases of the Dagestan conflict and Second Chechen War, and limits the analysis to the subsequent period of insurgency and counterinsurgency.[8] For each month, the occurence of violent events in each village was measured through automated text mining of the independent Memorial Group's "Hronika nasiliya [Chronicle of Violence]" event summaries (Memorial, 2009). Fuzzy string matching was used to geocode these violent events to the municipalities in sample, so as to account for alternate spellings in Russian and a host of local languages. The dataset includes over 28,102 unique reports on the dates, geographic coordinates, participants, and casualties of episodes of political violence and other forms of unrest distributed across these

[6] Quoted in Gammer (1998, 29).

[7] In alphabetical order, the republics are Adygea, Chechnya, Dagestan, Ingushetia, Kabardino-Balkaria, Karachaevo-Cherkessiya, and North Ossetia.

[8] The size of the dataset is 4,033 villages $\times 102$ months = 411,366 village-month observations.

villages and towns.

To capture the connective topology of the conflict zone, a dynamic network dataset was created, with individual villages as the units, and road distances as the connections between them. For comparison, I also created two alternative networks: one based on the assumption of independence between locations (insurgent logistics are self-sufficient), and one based on geodesic distances (insurgent logistics are highly flexible). A general description of the automated events and road network datasets is provided in the appendix, with a codebook and extensive technical details offered in an online supplement (`weblink`).

The dependent variable, *insurgent violence*, is measured as the occurrence of one or more insurgent attacks in a village-month. This definition encompasses several types of incidents, including terrorist attacks, hostage-taking, firefights (if initiated by insurgents), bombings, ambushes, and hit-and-run attacks. The incident must involve an "unlawful armed group" (*nezakonnoe vooruzhennoe formirovanie*) – a Russian designation that encompasses any armed faction, partisan formation, terrorist organization, military *dzhamaat* or other group established outside the norms and framework of state law. Targets of attack can be military, law enforcement, administrative or civilian in nature.

The opportunity for violence to spread is measured with a time-lagged spatial lag term, *distance from nearest attack*. This term captures the network proximity (road or geodesic) of each municipality to the nearest village where violence took place during the previous month. This specification enables direct inferences about the relationship between travel costs and violence, beyond what can be gleaned from more conventional spatial lags like the weighted sum of the dependent variable in neighboring areas ($\mathbf{W}y$). To evaluate the impact of counterinsurgency operations on the spread of violence, I include an indicator of whether a mop-up operation was observed in the village during the previous month. Also included are several structural determinants of target selection, such as population density, elevation and whether a village is directly accessible by road.[9] Table 1 shows a full list of variables considered, along with measurement details and summary statistics. Figure 2 shows a correlation matrix.

Following the logic of the epidemic model in Figure 1b – which postulates different theoretical mechanisms behind new versus recurring cases of insurgent violence (transmissibility versus recovery) – the empirical test assumes a first-order Markov Chain process, estimated through Generalized Additive Model (GAM) regression:

$$Pr_{i,t}(V) = \text{logit}^{-1}\big(\mathbf{x}_{i,t}\theta_0 + y_{i,t-1}\mathbf{x}_{i,t}\gamma + f(\text{Long}_i, \text{Lat}_i)\big) \tag{3}$$

where θ_0 is the set of regression coefficients for municipalities previously in a state of peace ($y_{i,t-1} = 0$) and $\theta_1 = \theta_0 + \gamma$ is the set of coefficients for municipalities previously in a state of violence ($y_{i,t-1} = 1$). A logit link function is used to relate the covariates $\mathbf{x}$ to the corresponding transition probabilities $Pr_{i,t}(P \rightarrow V), Pr_{i,t}(V \rightarrow V)$. Because insurgent activity is spatially heterogeneous, the model also includes a thin-plate spatial spline $f(\text{Long}_i, \text{Lat}_i)$ of the geographic coordinates of village i . The nonparametric spline is intended to capture long-term spatial variation in baseline risk, thus accounting for potential endemicity of insurgency to some particularly conflict-prone locations. The advantage of thin-plate splines is that they avoid the knot placement problems of conventional regression spline modeling, thus reducing the subjectivity of the model fitting process (Wood, 2003, 2006). Without the spline, the GAM collapses to a conventional logit regression. All other terms in the model are parametric, enabling inferences about increases in absolute and relative risk associated with changes in key independent variables. A more detailed discussion of this model is given

[9] Geospatial data on the road network in the Caucasus, as well as other spatial data of interest (population density, elevation, land cover), were taken from the U.S. Geological Survey's Global GIS Database (Hearn et al., 2005). The data include divided highways and two classes of undivided highways with at least 1 traffic lane in each direction: primary roads (connecting major urban centers) and secondary roads (connecting smaller municipalities). Streets and other roads connecting locations within municipalities are not included.

in the appendix and the online supplement to this article.

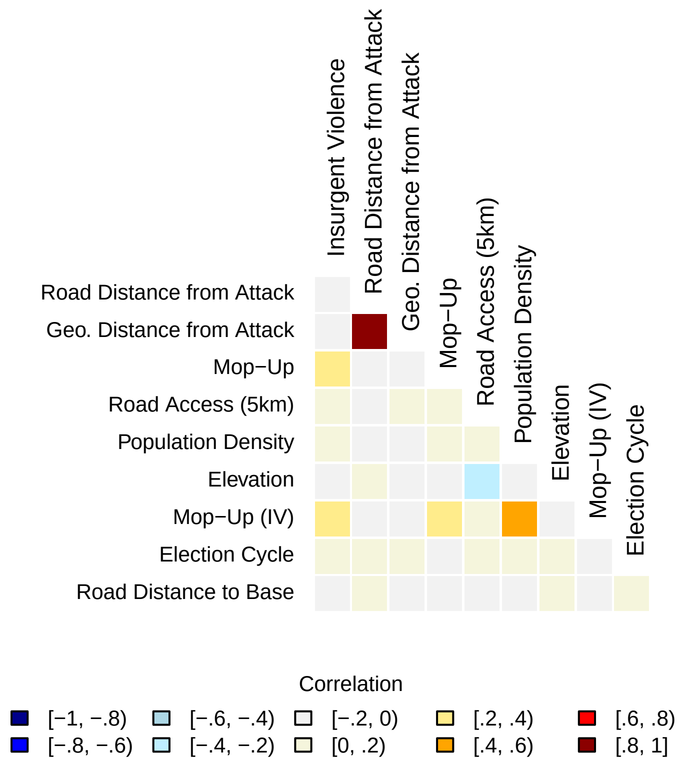


Figure 2: **Correlation Matrix**.

5 Empirical findings: How does violence spread?

Table 2 reports coefficient and standard error estimates for several empirical models of conflict dynamics in the Caucasus. To distinguish between the determinants of new and recurring cases of violence, results of each model are presented in two columns. The first evaluates the impact of covariates on locations initially in a state of peace, and the probability of their transitioning to violence ($P \rightarrow V$). The second does the same for locations initially experiencing violence, and the probability of their remaining in a state of unrest ($V \rightarrow V$). Three types of networks are considered: (1) a null network in which all locations are treated as independent, (2) a geodesic network in which insurgent mobility is not restricted to the existing transportation system, and (3) a road network in which movement between locations can only occur over existing road links. Substantively, these networks reflect propositions that insurgent logistics are – respectively – self-sufficient, flexible, or constrained. Momentarily limiting the analysis to Model 3, what can the data tell us about how conflict spreads?

Even in a volatile place like the North Caucasus, insurgent violence is a rare event. Since the end of the conventional phase of the Second Chechen War in mid-2000, its prevalence in the region has been limited to an average of 17 municipalities per month. In the overwhelming majority of cases, the risk of becoming exposed to fighting has been small – 99.7 percent of peaceful cases have remained peaceful from one month to next. While the remaining 0.3 percent has been enough to generate over a dozen new attacks each month, a disproportionate share of the violence has occurred on already-contested ground. If a village is the site of fighting one month, there is a one-in-four chance that it will remain violent during the next. Although 74.7 percent of restive cases immediately transition back to peace, recovering from violence is far more difficult than avoiding exposure in the first place. All other variables held constant at their median values, the probability of violence in a village targeted during the previous month is, on average, 26.7 times higher than in a village with no such history of violence.[10] The risk of exposure, furthermore, depends strongly on the logistical opportunities for fighting to spread.

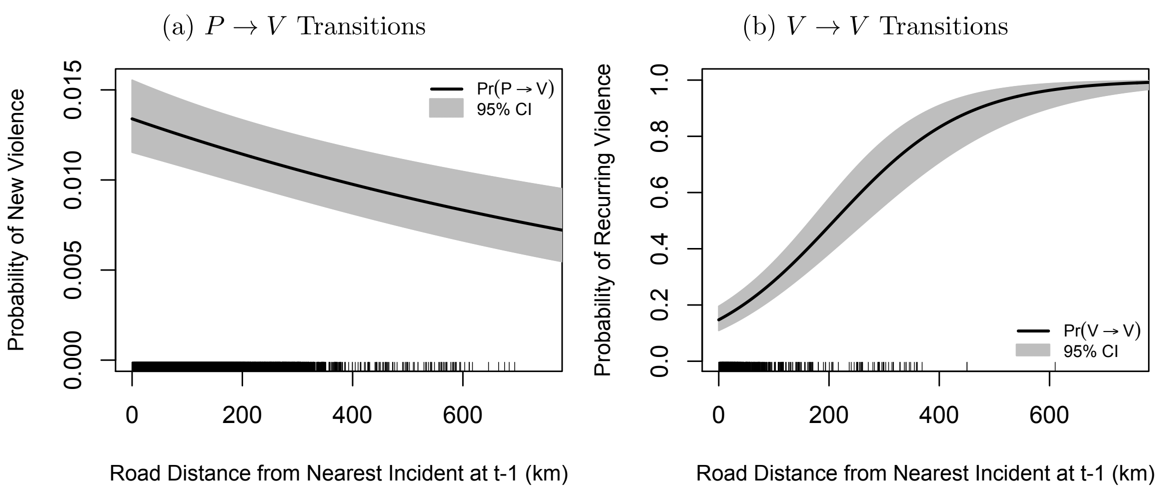
5.1 New violence in peaceful areas

The greater the proximity between violent and peaceful locations, the higher the risk of new attacks. In cases where a peaceful village remained at peace ($P \rightarrow P$), the road distance from the closest contested area was 179.2 km on average. Among villages where peace could not be sustained ($P \rightarrow V$), the average traveling distance was less than half this number: 75.1 km.

[10] Relative risk calculated from parameters of Model 3.

This relationship is shown graphically in Figure 3a, which plots the predicted probability of a $P \rightarrow V$ transition against road distances from the closest site where insurgent violence occurred at $t-1$.[11] In locations without an immediate history of violence, recent attacks in a village 500 km away place the risk of a local incident at 0.008, with a 95 percent confidence interval of (CI: 0.007, 0.010). If the nearest attack occurs just 1 km down the road, the local risk rises by over half to 0.013 (CI: 0.011, 0.015).

Figure 3: **New vs. recurring violence and road distance from nearest recent attack**



Irrespective of how close they are to other areas of current insurgent activity, villages with a physical connection to a road network are considerably more exposed to external threats than ones located off the grid. The risk of at least one new attack per month in villages within 5 km of a major road is over twice as high (CI: 1.74, 2.32) as in inaccessible villages, all other variables held constant at their median values.

Beyond the opportunities of insurgents to access and move between locations, a host of other unit-level risk factors influence how likely a village is to become exposed to violence. The probability of a $P \rightarrow V$ transition is quite high in villages where mop-up operations

[11] Unless otherwise indicated, all predicted probabilities and risk ratios are derived from Model 3. All other variables are held constant at median values.

have recently taken place. "Peaceful" villages subjected to such practices during the previous month are 7.56 (CI: 6.97, 8.16) times more likely to see at least one new insurgent attack than villages where government forces did not conduct any operations. Consistent with the epidemic framework, the risk of new violence is also found to be higher in densely-populated, low elevation municipalities. Compared to a village with 100 people living in a square kilometer of area, insurgent violence is on average 4.52 times (CI: 4.2, 4.8) more likely to occur in towns with a population density of 5,000/km^2, and almost 24 times (CI: 21.6, 25.9) more likely in cities with a density of 10,000/km^2. Likewise, violence is 4.4 times (CI: 4.1, 4.8) more likely in a village situated just 100 meters above sea level than in a mountain settlement at 1,000 meters.

5.2 Recurring violence in contested areas

As the second column of Model 3 suggests, the conditions that produce attractive targets for initial attack do not necessarily generate motivations for sustained fighting. While peace may be difficult to maintain in a violent neighborhood, violence is more likely to persist if initiated in a peaceful neighborhood. In cases where violent villages remained restive, the next closest site of insurgent activity was located 81.1 km away by road, on average. Where violent villages were able to transition back to peace, the average distance was 38.9 km. Figure 3b shows a model-based illustration of this relationship. The predicted probability of a $V \rightarrow V$ transition is 0.19 (CI: 0.15, 0.23) for a contested village just 1 km away from the another conflict site, but jumps to 0.86 (CI: 0.71, 0.94) for a village 500 km away.

What accounts for this seeming paradox? Why would low costs of travel facilitate the spread of violence to new locations, but inhibit the sustainability of violence elsewhere? The local expansion of armed conflict eventually hits an upper bound. In recent places of insurgent activity, close proximity to other active battlefronts creates a competition for resources. Even if their leadership is more mobile, guerilla groups rely operationally on rank-and-file militia who are recruited and employed locally, in small platoon-sized groups of up to 30 men (Schaefer, 2011, 243). When two contested villages are located 38.9 km away, both locations are likely to fall in the area of responsibility of a single group, and the same fighters cannot be in two places at once. To produce maximum strategic gain from limited resources, it is logistically simpler and operationally more efficient for a group to relocate its activities rather than to risk stretching itself thin. Relocation, however, requires that a choice be made among two or more alternative targets. This trade-off would be less pressing if the alternative theater was the operational turf of another group and did not compete for the same set of resources – as is more likely to be the case when the two battlefronts are 81.1 km away, much less 500 km. In the latter case, resources committed to one target are less likely to impact insurgents' ability to attack the other.

Once violence begins, the structural factors that informed initial target selection are quickly subsumed by conflict dynamics. Accessibility considerations like elevation and proximity to roads cease to be informative predictors of whether continued violence takes place. The impact of population density, while still significant, decreases in magnitude and increases in uncertainty. Other than the distance from nearest attack, the most important remaining factor appears to be the inflammatory impact of government action. In villages where mop-up operations were conducted in the previous month, the probability of continued insurgent violence was 0.53 (CI: 0.45, 0.62), almost 70 percent higher than where government forces exercised restraint.[12]

[12] This finding contrasts with recent empirical work by Lyall (2010), who found that mop-up operations – when conducted by coethnics – can suppress insurgent resistance. This difference can be explained in part by data and methodology choices. Lyall uses a matched dataset of 145 paired villages in Chechnya only, with a time range of January 2000 to December 2005. The current study uses a panel dataset of 4,033 villages in seven republics between July 2000 and December 2008, a different statistical model, and examines the impact of mop-ups in general, not disaggregated by ethnic group.

6 Do logistical constraints matter?

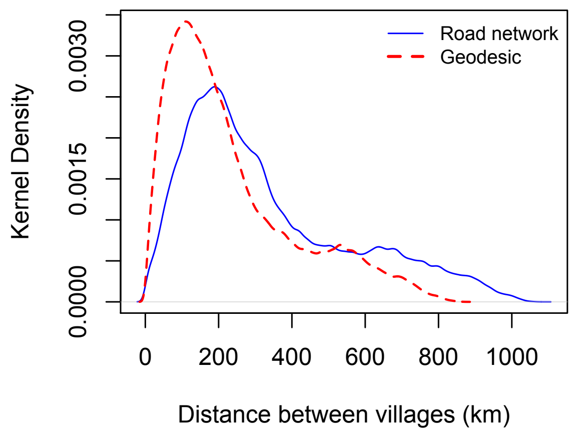
Although physical connections between municipalities may help explain the expansionary and self-limiting dynamics of insurgent violence, one may ask whether (and how) information on the structure of a road network changes the inferences we make and improves our ability to predict future events. Are geodesic distances – which assume flexible, unconstrained insurgent logistics – so unrealistic as to cast doubt on the findings of so much disaggregated conflict research? What if we were to dispose of network connectivity assumptions altogether, essentially treating each location as independent and insurgent logistics as self-sufficient? The following section demonstrates that – although geodesic distance can be useful as an imperfect proxy for more realistic types of geographic connections – the geodesic assumption can also be a source of systematic bias. By underestimating the costs of travel between locations, geodesic models tend to overpredict the transmissibility of violence. Road network data can help us build models with more conservative estimates, which outperform both the null and geodesic models in goodness-of-fit and the accuracy of in- and out-of-sample predictions.

Are road network distances significantly different from geodesic ones? Figure 4 shows a kernel density plot of 16,265,089 shortest-path distances connecting the 4,033 municipalities in the study region, as calculated by simple geodesic distance (dashed line) and road network distance (solid line).[13] Although the the distributions are similar in shape – slightly bimodal, with a heavy right tail – the geodesic distance estimates are consistently shorter. If the road network calculates the average shortest-path distance between two North Caucasus municipalities to be 334.17 km (SD: 195.35), its geodesic counterpart is nearly 100 km less: 235.69 km (SD: 177.7). Much of this difference is due to the rugged, mountainous and forested terrain of the Caucasus, which forces roads to follow circuitous paths along valleys,

[13] Geodesic distances were calculated on a GRS 80/WGS 84 spheroid with a UTM 39N projection, converted to kilometers.

rivers and other natural topological features. While a well-connected, regular road network in flat terrain would almost surely yield fewer discrepancies, such environments are relatively uncommon in the study of civil war.

Figure 4: **Road vs. geodesic distance estimates**



Do different distance measures have different empirical implications? The coefficients reported in Table 2 are of the same sign, approximate size and significance level, although the geodesic model estimates that *distance from nearest attack* has a slightly larger effect on the probability of $P \rightarrow V$ transitions and a slightly more uncertain effect on $V \rightarrow V$ transitions. The full extent of this difference, however, is better illustrated through simulation. A key statistic in epidemiology is the basic reproduction number, defined as the expected number of secondary cases produced by a single infection in a completely susceptible population. In the current case, we may arrive at this statistic by asking: if violence erupts in a single location and all others are initially at peace, how many locations are likely to experience violence as a direct result of the initial outbreak?

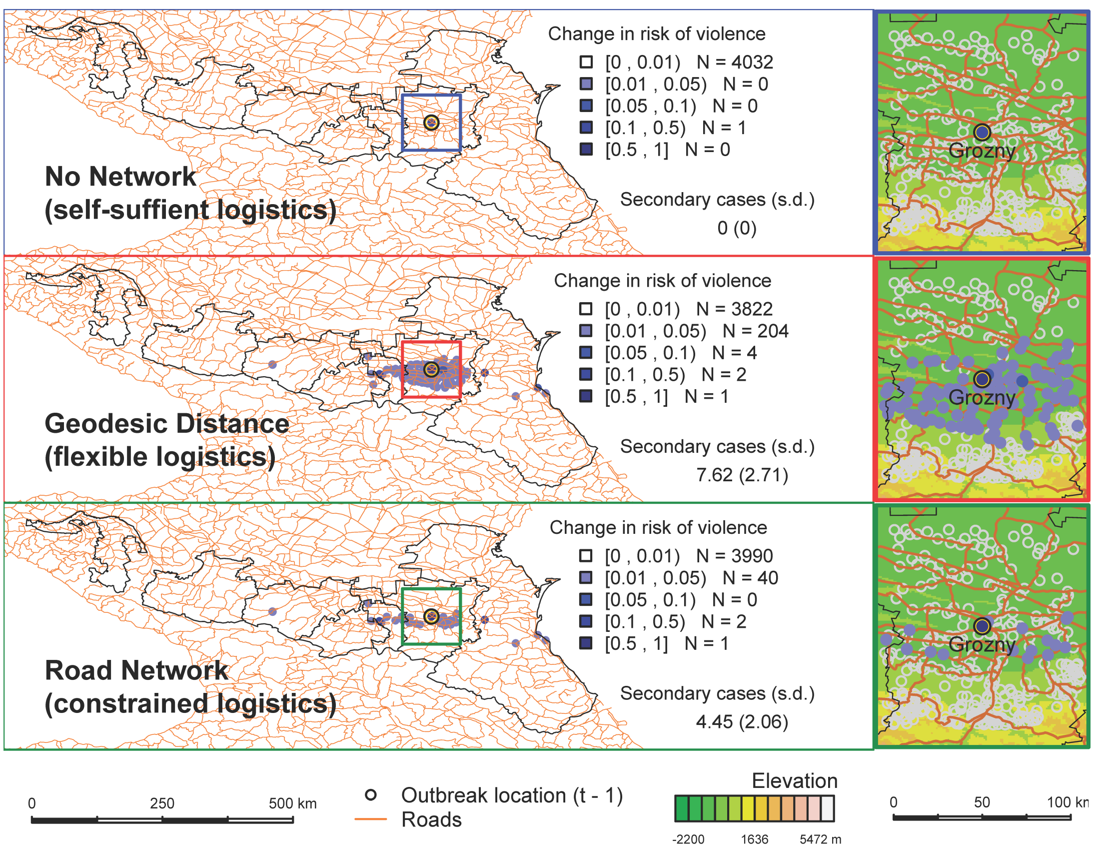
Using the results of Models 1-3, I simulated such an outbreak for each of the three networks. The Chechen capital of Grozny was selected as "patient zero" – the initial target of insurgent attack at a time of region-wide peace.[14] Based on this outbreak location and the connective structure of the affected region – non-existent for the null model, unconstrained for the geodesic model, and constrained to the transportation network for the road model – the probability of insurgent violence was predicted in every village a month after the initial attack. The resulting "disease maps" are shown in Figure 5. Locations where the probability of new violence ($P \rightarrow V$) increased the most as a result of the Grozny attack are shown in darker circles, with a close-up inset showing the immediate vicinity of the incident. Based on these changes in transition probabilities, I ran 10,000 simulations to determine the expected locations and numbers of new insurgent attacks. The mean and standard deviations of these counts are reported in the Figure as "Secondary cases."

As one might expect, the null model (self-sufficient logistics) predicts that the initial attack will be an isolated incident with no consequences for the region, other than increasing the chances of recurring violence in Grozny itself. The geodesic model (flexible logistics) predicts a much broader pattern of contagion, which significantly raises the probability of new violence in over 200 municipalities, and generates 7.62 new contested areas on average. The road model (constrained logistics) also estimates a fairly diffuse regional impact, but paints a less alarming picture of its extent. The probability of transition rises significantly in just over 40 locations, with a high risk of recurrence in the outbreak's place of origin. The expected number of secondary cases drops to a more conservative 4.45.

Which diffusion model is most accurate? Table 2 reports two sets of model-level diagnostics: Akaike Information Criterion (AIC), a goodness-of-fit statistic for non-nested models, which balances an analysis of deviance against a penalty for overfitting; and the area under the receiver-operator characteristic curve (AUC), which can be interpreted as the probability that – for a randomly-chosen pair of violent and non-violent villages – the model will assign

[14]For the outbreak simulation, all non-conflict variables were held constant at their observed values from December 2008.

Figure 5: **Outbreak simulation**. Regions, from west to east, are: Adygea, Karachaevo-Cherkessiya, Kabardino-Balkaria, North Ossetia, Ingushetia, Chechnya and Dagestan.



a higher predicted probability to the violent case. The AUC is used for the evaluation of both in-sample prediction accuracy and repeated subsampling cross-validation, where – for each of 100 trials – a randomly selected 10 percent of the monthly cross-sections were set aside prior to running the models shown in Table 2, and these out-of-sample data points were used to test the accuracy of outcomes predicted. The road model consistently outperforms its alternatives in each test: it has superior overall fit (lower AIC), and produces the most accurate in- and out-of-sample predictions (higher AUC). While differences in model-level diagnostics are less profound than that revealed by the simulation of specific counterfactuals, the relative performance of the road model is consistently superior to the alternatives. In the Caucasus case, at least, more conservative estimates of contagion also appear to be the most valid.

7 Robustness checks

As with all empirical work, the findings presented above need to be treated with some caution. The current section reports the results of sensitivity analyses that address two potential substantive and methodological concerns. First, although recent instability has left few parts of the Caucasus unscathed, the locus of insurgency for much of the post-Soviet period has been in Chechnya. While the spatial spline accounts for many sub-regional and trans-regional differences in the distribution of violence, the models in Table 2 do not explicitly account for fixed differences in the distribution *between* the seven autonomous republics.[15] The qualitative literature suggests that these differences may be substantial – republican interior ministries operate under separate chains of command, while even the administrative subdivisions (*vilayahs*) of Doku Umarov's Caucasus Emirate roughly correspond to the borders of the seven Russian republics (Hahn, 2008, 18). To address this concern, I re-fitted the

[15]The author is grateful to an anonymous reviewer for voicing this important critique.

three models with regional fixed effects. As reported in Table 3 and discussed more fully in the online supplement, the inclusion of regional fixed effects changes neither the substantive results of the models, nor their relative levels of fit and accuracy.

The second robustness check addresses potential concerns over the causal sequence of insurgency and counterinsurgency, and the strategic nature of this interaction. The specification used in Table 2 included an indicator of whether a mop-up operation was observed in a village during the previous month, which effectively assumes that insurgents respond to recent government violence, but do not consider the effect of their own actions on future reprisals. Government violence, however, can be a response to insurgent activity as well as a trigger, and insurgent target selection is likely to reflect *expectations* of counterinsurgency operations as much as their recent history. To formally account for these expectations, I use federal election cycles as an instrumental variable for counterinsurgency activity, following a well-known approach to the study of policing and crime (Levitt, 1997). During campaign seasons for the State Duma (quadrennial, October-December) and Presidency (quadrennial, January-March), MVD troops assume additional guard duties around electoral commissions, critical infrastructure and public spaces, which diverts resources away from larger-scale operations to identify and arrest potential insurgents.[16] Because these periodic resource reallocations are grounded in fixed political cycles rather than fluctuations in insurgent activity, the election campaign season offers an exogenous source of variation behind patterns of counterinsurgency. The first stage regression models are reported in Table 4 and the three models re-estimated using an instrumented version of the mop-up variable are shown in Table 5. Results are largely unchanged despite slightly wider confidence bounds. The relative fit and accuracy of the road model are still superior to the rest.

[16] "V Ingushetii i Chechnye MVD perevedeno na usilennyi rezhim sluzhby v svyazi s vyborami v Gosdumu RF [In Ingushetia and Chechnya the MVD have transitioned to a more robust security regime in connection with State Duma elections]," *Kavkazskiy uzel*, 1 December 2007.

8 Conclusion

A popular saying among military planners, originally attributed to Admiral Hyman Rickover, is that "the art of war is the art of the logistically feasible." Existing research on the diffusion of violence on the local level of civil war has tended to under-specify the theoretical mechanisms by which conflict can spread, and overlook the real-world logistical constraints that combatants face on a daily basis. This paper attempted to address both of these problems by taking a closer look at the role of road networks in the diffusion of insurgent activity.

By explicating the logic of diffusion in a simple epidemic model and exploiting new disaggregated data on violence and road networks in the North Caucasus, the preceding analysis challenges the conventional view that insurgent activity is relatively unconstrained by logistical infrastructure. Roads are, at best, a mixed blessing. They increase access to otherwise isolated hotspots, but can also turn accessible villages into attractive insurgent targets of opportunity, shape the costs of sustaining and expanding operations, and facilitate the transmission of violence between locations. However, the epidemic approach also uncovers a self-limiting dimension to the spread of insurgency: by increasing the ease of communication, road connections can intensify competition for limited military resources between nearby battlefronts and magnify opportunity costs of sustained fighting. At the local level, this dynamic makes the relocation of insurgent activity more likely than its expansion.

This paper also makes a methodological case for the formal incorporation of logistical constraints into the empirical study of civil war. A reliance on more conventional measures of Euclidean or geodesic distance can bias downward the estimated costs of communication and overpredict the transmissibility of violence between neighboring locations. Particularly in rugged areas where straight-line distances assume that combatants can walk through mountains, the use of road network distances can yield more conservative inferences and more accurate predictions of how violence spreads.

Appendix

Automated event coding

Since the original Memorial data are in raw text format, automated text analysis was used to mine the Memorial timeline for dates, locations, actors involved, casualty tolls, and types of incidents. The data extraction strategy I employed differs from traditional automated approaches in several ways. First, dictionary-based event coding algorithms typically use parsing techniques or pattern recognition to code incidents in a "who-does-what-to-whom" format, of which category typologies like VRA and TABARI are prime examples (Schrodt and Gerner, 1994; Schrodt, 2001; Gerner et al., 2002; King and Lowe, 2003; Shellman, 2008). I opted for a somewhat simpler approach based on Boolean association rules and indexing algorithms (Han and Kamber 2001, 230-236; Kim et al. 2001). While not appropriate for all applications, this approach is far more efficient for data-mining highly structured event summaries of the sort that comprise the Memorial timeline – where all entries are of approximately the same length (1-2 sentences) and content (date, location, what happened, who was involved). Second, while various studies have shown that reliance on a single news source in event data analysis can mask important differences in media reporting, most previous uses of events data have relied on only one news source (Reeves et al., 2006; Davenport and Ball, 2002). The advantage of Memorial's event summaries is that they compile daily reports from international news wires, Russian state and local newspapers, news websites, radio and television broadcasts, and independent reporters, permitting a diverse approach to corpus building that reduces the risk of reporting bias.[17]

From these raw data, the Text Mining (`tm`) package in the R statistical language was used to assemble a corpus of over 38,000 text documents, perform natural language processing (removing word order and Russian stop words) and create a document-term matrix (Feinerer et al., 2008). Two custom dictionaries were used to (1) classify events[18] and (2) automatically georeference them against a universal sample of 4,033 cities, towns and villages listed in the U.S. National Geospatial Intelligence Agency's GNS database of populated places in the seven North Caucasus Republics (Dagestan, Chechnya, Ingushetia, North Ossetia, Kabardino-Balkaria, Karachaevo-Cherkesiya, Adygea). In all, 28,102 unique events were recorded between January 2000 and September 2009, representing as close to a comprehensive sample of state and nonstate violence in Russia as open sources currently permit.[19] The time window was then narrowed to include only the insurgency phase of the conflict (July 2000 - December 2008).

[17] A natural concern with this, like all disaggregated events datasets, is that media are more likely to report incidents located in accessible areas (Raleigh and Hegre, 2009, 234). This problem is addressed somewhat by Memorial's reliance on reports from human rights observers and local independent sources – who benefit from greater access to isolated areas than mass media organization with relatively few local ties.

[18] Full codebook and dictionary are provided in an online supplement.

[19] This statistic can be compared with 925 Russian events for the post-Soviet period in the Global Terrorism Database (LaFree and Dugan, 2007) and 14,177 events in the North Caucasus dataset collected by O'Loughlin and Witmer (2011)

Road network data

To model the spread of insurgent violence as a network process and construct spatially-lagged variables, I measured the accessibility between populated places with an origin-destination (OD) matrix $\mathbf{D}$, in which entries d_{ij} are shortest-path distances (km) between places i and j along the local network of roads. OD matrices have been the subject of a vast literature in urban planning and transportation engineering,[20] but have not – to my knowledge – been widely used in political geography, despite the many advantages of network relative to geodesic distance. Although the calculation of road network distances is far more computationally intensive than their planar or spherical counterparts, OD matrices can be estimated with Python scripts, Java programs or ArcGIS extensions (Steenberghen et al., 2009). For my data, I used a geoprocessing script that relies on ArcMap's Network Analyst engine.[21] The result is a dense $7,583 \times 7,583$ matrix, with 57,517,056 shortest-path road distances between villages. Used in the preceding analysis is a $4,033 \times 4,033$ submatrix, which covers only the seven autonomous republics.

Valued network data are often dichotomized for ease of interpretation (by distinguishing between neighbors and non-neighbors) and computational efficiency (the valued matrix is over 3GB in size). However, dichotomization also risks the loss of potentially important information (Thomas and Blitzstein, 2009). Because the epidemiological model assumes continuous measures of network distance, I avoided the use of dichotomizing cutpoints and preserved the continuous distance data.

Markov transition model with spatial spline

Following Amemiya (1985) and Jackman (2000), a logit link function was used to estimate the transition probabilities in Figure 1b. The probability that a peaceful village i transitions to violence between times $t-1$ and t is expressed as

$$Pr_{i,t}(P \rightarrow V) = Pr(y_{i,t} = 1 | y_{i,t-1} = 0, \mathbf{x}_{i,t}) = \text{logit}^{-1}(\mathbf{x}_{i,t}\theta_0) \tag{4}$$

and the probability that a violent village remains violent is

$$Pr_{i,t}(V \rightarrow V) = Pr(y_{i,t} = 1 | y_{i,t-1} = 1, \mathbf{x}_{i,t}) = \text{logit}^{-1}(\mathbf{x}_{i,t}\theta_1) \tag{5}$$

where $y_{i,t-1} = 1$ indicates that location i experienced insurgent violence at time $t-1$, and $y_{i,t-1} = 0$ otherwise. θ_0 and θ_1 are sets of regression coefficients that capture the conditional effects of the covariates $\mathbf{x}$ (see Table 1 for a full list) under the two possible current states. These equations are reduced to

$$Pr_{i,t}(V) = Pr(y_{i,t} = 1 | \mathbf{x}_{i,t}) = \text{logit}^{-1}(\mathbf{x}_{i,t}\theta_0 + y_{i,t-1}\mathbf{x}_{i,t}\gamma) \tag{6}$$

[20] See Cherkassky et al. (1996); Zhan and Noon (1998)

[21] A 5km buffer was used to determine which villages were connected to the road network. For municipalities further off the grid (17% of total), the script calculated the geodesic distance to the closest on-road village, and used the latter's distance values, penalized by the additional travel-to-road distance.

where $\theta_1 = \theta_0 + \gamma$. Finally, the expression in (5) is used as the parametric portion of a GAM model

$$Pr_{i,t}(V) = \text{logit}^{-1}\big(\mathbf{x}_{i,t}\theta_0 + y_{i,t-1}\mathbf{x}_{i,t}\gamma + f(\text{Long}_i, \text{Lat}_i)\big) \tag{7}$$

where $f(\text{Long}_i, \text{Lat}_i)$ is a thin-plate regression spline of the geographic coordinates of village i. For a detailed discussion of this class of models, see Wood (2003, 2006) and the online supplement to this article.

Table 1: **Measurement and summary statistics.**

Dependent variable	Measurement	Range	Mean	Median	S.D.
State (violent/peaceful)					
Insurgent $\text{Violence}_{i,t}$	1 if at least one episode of insurgent violence was observed in village i during month t; 0 otherwise	[0,1]	0.004	0	0.06
Covariates					
Conflict dynamics					
Distance from nearest $\text{attack}_{i,t-1}$	$\min(\mathbf{w}_i \text{Insurgent Violence}_{j \neq i,t-1})$ where $\mathbf{w}_i$ is a vector of distances between village i and all other villages j (km)				
	Road:	[0, 1084.2]	178.32	106.87	245.12
	Geodesic:	[0, 869.77]	142.64	70.88	205.99
$\text{Mop-up}_{i,t-1}$	1 if at least one mop-up operation was observed in village i during previous month; 0 otherwise	[0, 1]	0.003	0	0.06
Structural factors					
Road accessibility_i	1 if village i is within 5 km of major road; 0 otherwise	[0, 1]	0.83	1	0.38
Population density_i	number of people per square kilometer	[0, 11576]	179.12	17	650.62
Elevation_i	elevation of village i in meters above sea level	[-31, 2818]	827.39	678	701.91

Table 2: **Markov transition models**. GAM logit coefficients and standard errors reported. Dependent variable is incidence of insurgent violence. Unit of analysis is the village-month. Model 3 used for all simulations, unless otherwise indicated.

	(1) No Network		**(2) Geodesic Network**		**(3) Road Network**	
	New $P \rightarrow V$	Recurring $V \rightarrow V$	New $P \rightarrow V$	Recurring $V \rightarrow V$	New $P \rightarrow V$	Recurring $V \rightarrow V$
(Intercept)	-6.7203 (0.2523)***	-4.4109 (0.6023)***	-6.5578 (0.2523)***	-4.3603 (0.6020)***	-6.5465 (0.2530)***	-4.6710 (0.6114)***
Geodesic DFA (t-1)			-0.0013 (0.0002)***	0.0066 (0.0017)***		
Road DFA (t-1)					-0.0009 (0.0002)***	0.0066 (0.0010)***
Road access	0.7146 (0.1416)***	0.5549 (0.5381)	0.7136 (0.1416)***	0.5428 (0.5380)	0.7028 (0.1416)***	0.7507 (0.5450)
Pop. density	0.0004 (2e-05)***	0.0003 (4e-05)***	0.0004 (2e-05)***	0.0003 (4e-05)***	0.0004 (2e-05)***	0.0003 (4e-05)***
Elevation	-0.0019 (0.00022)***	-0.0005 (0.0004)	-0.0019 (0.0002)***	-0.0006 (0.0004)	-0.0019 (0.0002)***	-0.0006 (0.0004)
Mop-ups (t-1)	2.114 (0.1102)***	1.0350 (0.2575)***	2.0954 (0.1099)***	1.0425 (0.2566)***	2.1043 (0.1099)***	0.9109 (0.2594)***
Spline(Long,Lat)	EDF: 28.4315***		EDF: 28.3809***		EDF: 28.4118***	
AIC	14,965.62		14,910.95		14,883.54	
AUC (in-sample)	0.9258		0.9265		0.9267	
AUC (out-of-sample)	0.9193 (SD: 0.0141)		0.9196 (SD: 0.0143)		0.9201 (SD: 0.0142)	
N	406,727		406,727		406,727	

DFA: distance from nearest recent attack; EDF: Estimated degrees of freedom; $^{*}p \leq 0.05$, $^{**}p \leq 0.01$, $^{***}p \leq 0.001$
Out-of-sample AUC statistics are averaged over 100 random subsample cross-validation tests, with 90%-10% splits.

Table 3: **Robustness check: Republic-level fixed effects.**

	(4) No Network		**(5) Geodesic Network**		**(6) Road Network**	
	New $P \rightarrow V$	Recurring $V \rightarrow V$	New $P \rightarrow V$	Recurring $V \rightarrow V$	New $P \rightarrow V$	Recurring $V \rightarrow V$
(Intercept)	11.8464 (3.4674)***	14.1803 (3.5061)***	11.258 (3.421)***	13.4856 (3.4615)***	11.5088 (3.4458)***	13.4278 (3.4877)***
Geodesic DFA (t-1)			-0.0013 (2e-04)***	0.0061 (0.0017)***		
Road DFA (t-1)					-9e-04 (2e-04)***	0.0065 (0.001)***
Road access	0.7066 (0.1428)***	0.5405 (0.4581)	0.7044 (0.1428)***	0.528 (0.4581)	0.6947 (0.1427)***	0.7228 (0.4658)
Pop. density	4e-04 (2e-05)***	3e-04 (3e-05)***	4e-04 (2e-05)***	3e-04 (3e-05)***	4e-04 (2e-05)***	3e-04 (3e-05)***
Elevation	-0.0018 (2e-04)***	-5e-04 (3e-04)	-0.0018 (2e-04)***	-6e-04 (3e-04)	-0.0019 (2e-04)***	-6e-04 (3e-04)
Mop-ups (t-1)	2.0934 (0.1107)***	1.0358 (0.1343)***	2.0761 (0.1104)***	1.0442 (0.1335)***	2.0844 (0.1104)***	0.9146 (0.1388)***
Spline(Long,Lat)	EDF: 28.4989***		EDF: 28.4433***		EDF: 28.4726***	
AIC	14,933.17		14,880.12		14,853.07	
AUC (in-sample)	0.9267		0.9275		0.9277	
AUC (out-of-sample)	0.9163 (SD: 0.0134)		0.9172 (SD: 0.0135)		0.9175 (SD: 0.0133)	
N	406,727		406,727		406,727	

Table 4: **Robustness check: First stage IV regression.** Logit coefficients and standard errors reported. Dependent variable is incidence of mop-up. Instrumental variable is federal election cycle. Unit of analysis is the village-month.

	(4) None	**(5) Geodesic**	**(6) Road**
(Intercept)	-5.5273***	-4.9337***	-5.1325***
	(0.1653)	(0.1699)	(0.1693)
Election cycle	-0.3959***	-0.4017***	-0.3905***
	(0.0952)	(0.0951)	(0.0952)
Road distance to base	-0.0141***	-0.0148***	-0.0143***
	(9e-04)	(9e-04)	(9e-04)
Geodesic DFA (t-1)		-0.0052***	
		(4e-04)	
Road DFA (t-1)			-0.0027***
			(3e-04)
Road access	0.9896***	0.9486***	0.9405***
	(0.1557)	(0.1561)	(0.156)
Pop. density	0.0003***	0.0003***	0.0003***
	(1e-05)	(1e-05)	(1e-05)
Elevation	-0.0011***	-0.0012***	-0.0011***
	(1e-04)	(1e-04)	(1e-04)
Insurgent violence (t-1)	3.5051***	3.1145***	3.3100***
	(0.0771)	(0.0795)	(0.0776)
AIC	14,257.884	13,944.882	14,099.744
N	405,717	405,717	405,717

Table 5: **Robustness check: Second stage IV regression.** Instrumented version of mop-up variable.

	(7) No Network		**(8) Geodesic Network**		**(9) Road Network**	
	New $P \rightarrow V$	Recurring $V \rightarrow V$	New $P \rightarrow V$	Recurring $V \rightarrow V$	New $P \rightarrow V$	Recurring $V \rightarrow V$
(Intercept)	-6.7476	-4.7537	-6.5817	-4.7968	-6.5852	-5.0751
	(0.2621)***	(0.5306)***	(0.2614)***	(0.5331)***	(0.2622)***	(0.5612)***
Geodesic DFA (t-1)			-0.0011	0.009		
			(0.0002)***	(0.0017)***		
Road DFA (t-1)					-0.0008	0.0084
					(0.0002)***	(0.001)***
Road access	0.7386	0.282	0.7314	0.2706	0.7248	0.6282
	(0.1414)***	(0.4563)	(0.1414)***	(0.4553)	(0.1414)***	(0.4786)
Pop. density	0.0004	0.0001	0.0003	5e-05	0.0003	0.0001
	(2e-05)***	(0.0001)	(2e-05)***	(0.0001)	(2e-05)***	(0.0001)
Elevation	-0.002	-0.0001	-0.002	-0.0002	-0.002	-0.0003
	(0.0002)***	(0.0003)	(0.0002)***	(0.0003)	(0.0002)***	(0.0003)
Mop-ups (IV) (t-1)	7.4754	5.4154	10.687	5.7121	7.2682	3.9684
	(2.9935)*	(1.1361)***	(2.8001)***	(1.0616)***	(2.7181)**	(1.1634)***
Spline(Long,Lat)	EDF: 28.5549***		EDF: 28.4922***		EDF: 28.5357***	
AIC	15,241.8		15,174		15,153.55	
AUC (in-sample)	0.9218		0.9228		0.9230	
AUC (out-of-sample)	0.9151 (SD: 0.0149)		0.9153 (SD: 0.0162)		0.9158 (SD: 0.0156)	
N	405,717		405,717		405,717	

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