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Multiplex Network Ties and the Spatial Diffusion of Radical Innovations: Martin Luther's Leadership in the Early Reformation

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Abstract

This article analyzes Martin Luther's role in spreading the early Reformation, one of the most important episodes of radical institutional change in the last millennium. We argue that social relations played a key role in its diffusion because the spread of heterodox ideologies and their eventual institutionalization relied not only on private "infection" through exposure to innovation but also on active conversion and promotion of that new faith through personal ties. We conceive of that process as leader-to-follower directional influence originating with Luther and flowing to local elites through personal ties. Based on novel data on Luther's correspondence, Luther's visits, and student enrollments in Luther's city of Wittenberg, we reconstruct Luther's influence network to examine whether local connections to him increased the odds of adopting Protestantism. Using regression analyses and simulations based on empirical network data, we find that the combination of *personal/relational diffusion* via Luther's multiplex ties and *spatial/structural diffusion* via trade routes fostered cities' adoption of the Reformation, making possible Protestantism's early breakthrough from a regional movement to a general rebellion against the Roman Catholic Church.

Keywords

diffusion, social networks, opinion leaders, contagion models, social change

We know intuitively that leadership can make an enormous contribution to the spread of new ideological movements. An extensive literature on social diffusion explores the role of opinion leaders, or "influencers," on the spread and adoption of innovations (Rogers 2003; Valente 1996; Watts and Dodds 2007). Via the information they pass on and the influence they exercise, opinion leaders generate positive externalities: their actions increase the odds of adoption by others. Research shows that personal outreach and public appearances can be an important way in which leaders influence voters (Selb and Munzert 2018), spread radical political movements (Brooke and Ketchley 2018), and create labor movement organizations (Hedström,

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Sandell, and Stern 2000). In this light, our article provides new insight into Martin Luther's personal influence on the spread of the Reformation—a cause long considered important by historians and biographers but never systematically tested.

Empirically identifying the unique effect of opinion leaders is difficult: leaders are embedded in macro and institutional contexts, and it is challenging to parse out the characteristics of individuals who uniquely contributed to adoption of a movement. Moreover, the role of opinion leaders can be overstated. In many instances of diffusion, prominent individuals are not necessary to induce social change (Watts and Dodds 2007).

Social network concepts and historical network data can help provide answers.[1] Leaders of movements try to influence people to adopt their innovations, and via their network ties we can capture the scope of their influence. However, to parse out their influence from other factors we need significant relational data about leaders, their social context, and their network—who they knew, what they did, where they went (Brughmans, Collar, and Coward 2016; Erikson 2013; Manzo et al. 2018; Watts and Dodds 2007). Leaders create ties to different people and places, which provides a unique source of analytic leverage. We can use these network data to simulate the spread of a movement with and without the leader's network, thus exploring the unique role played by the leader.

We use social network theory and historical network data to analyze Martin Luther's role in spreading the early Protestant Reformation, one of the most important episodes of radical institutional change in the last millennium. Luther sparked the Reformation through public controversies and was a tireless proponent through his publishing activities. Most accounts of the spread of the Reformation stress the role of printed material. But how important was printing compared with Luther's personal influence in the Reformation's early breakthrough? Whereas printing would have facilitated the spread of the Reformation chiefly through the mechanism of informational diffusion, relational diffusion may have been more important in the breakout phase of the movement. However, it has been neglected in explaining the rise of Protestantism.

We argue that social relations played a key role in the diffusion of the early Reformation because the spread of heterodox ideologies and their eventual institutionalization relies not only on private "infection" by exposure to a novel idea, but on active conversion to and the promotion of that new faith through personal ties. Radical movements tend to diffuse via social linkages between actors rather than merely through information (Centola 2018; Hedström 1994; Hedström et al. 2000; Kim and Pfaff 2012; McAdam and Diani 2003; Siegel 2009). We reconstruct Luther's influence network to examine whether his local connections increased the odds of adopting Protestantism. We conceive of that process as leader-to-follower directional influence originating with Luther and flowing to local elites through personal ties. Luther played the role of a global opinion leader based in Wittenberg. He had ties with local elites in towns across Central Europe, who, in turn, exerted influence in their towns. Put simply, our argument is that social influence flowed from a central opinion leader through social ties to cities that were potential adopters: Luther → local elites → cities.

The question of Luther's specific role in the spread of the Reformation has been debated in the historical literature (for a review, see Becker, Pfaff, and Rubin 2016), but we shed new light on the issue by assembling unique sources of data. First, we use recently-digitized data capturing multiple links Luther forged with individuals in cities of the Holy Roman Empire (hereafter, HRE): his correspondence, the places he visited, and the students he taught. This generates an egonetwork centered on Luther with multiplex ties to alters. As Szell and Thurner (2013:1) explain, "Essential to understanding the behavior of humans within their socioeconomical environment is the observation that they simultaneously play different roles in various interconnected social networks, such as friendship networks, communication networks, family, or business networks. The

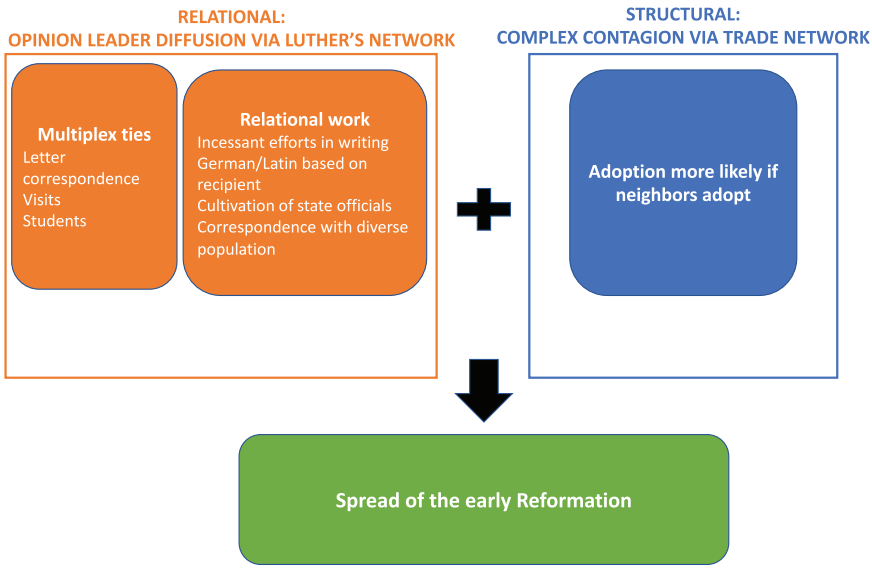

Figure 1. Summary of Mechanisms of Diffusion in the Early Reformation

superposition of several networks on the same set of nodes . . . is called a multiplex network" (see also Wasserman and Faust 1994). Second, we map the trade route network between German cities in the sixteenth century to capture the spatial diffusion of ideas. Third, we use detailed city-level data previously collected by Rubin (2014) to model the odds of adoption: these data include population size, printing activity, and, most importantly, whether a city adopted the Reformation.

We recognize that Luther's influence would not have been the only factor that influenced adoption, and other diffusion processes were operating. Our argument is that *personal/relational diffusion* via Luther's multiplex ties combined with *spatial/structural diffusion* via trade routes to help Protestantism's early breakthrough from a regional reform movement to a general rebellion against the Roman Catholic Church. Figure 1 illustrates this idea. It depicts a diffusion story of multiplex networks with multiple diffusion processes. Multiplex ties point to how Luther as an opinion leader mobilized his personal network as an ensemble of letters, visits, and student relationships, and also how Luther's network blends with the spatial network to create complex contagion processes operating at the intersection of information flow and social influence. Because diffusion via Luther's personal network is a different process than spatial diffusion by word-of-mouth or imitation of neighbors, we speak of "multiple processes."

Luther's influence was crucial, but the evidence shows that the early Reformation diffused beyond the scope of his personal connections and geographic region. A sociological explanation for how the Reformation spread combines Luther's personal network with a network of on-the-ground relations among cities through which the Reformation's reach could have expanded as his ideas took root. More generally, we argue that simple diffusion models that flatten networks into uniplex ties, or ignore tie characteristics, are inadequate to explain large-scale social change. Instead, one needs to consider how multiple networks can work in conjunction to propel diffusion.

INFLUENCE, MULTIPLE DIFFUSION, AND SPREAD OF THE REFORMATION

The focus on Luther is justified by the fact that no other figure in the early Reformation

approached his standing or visibility. Luther can be thought of as a special kind of opinion leader, a "hyper-influential" person who could sway many people through persuasion and example.[2] Because of his fame and indefatigable efforts to spread the Reformation, Luther's life is surprisingly well-documented. He left behind a trove of letters, a record of his travels and visits to places, and matriculation lists of the students who studied with him. As one eminent historian noted, "[t]here is probably no other sixteenth-century figure who has left such a wealth of ego-documents as Luther" (Roper 2010:283). These records allow us to reconstruct influence networks.

We argue that Luther's influence mattered because it linked the Reformation movement's central actor to elite residents in Central European cities who were literate, well-informed, and socially connected. In addition to Luther's personal influence, we argue that spatial proximity also mattered because the adoption of Protestantism by neighboring cities would have increased the odds of adoption as well. Diffusion is facilitated by social exchange, whether through emulation, learning, isomorphism (Christakis and Fowler 2007, 2008; Palloni 2001; Strang and Soule 1998), or coordination among adopters ("safety in numbers," as suggested by Cantoni [2012]). To capture spatial diffusion, we measure a city's position in the trade route network. To capture social influence, we restrict our analysis to Luther's correspondence/visits/ties made prior to 1523, when the Protestant reforms were first formally adopted. Focusing on the early period helps isolate Luther's influence, because prior to 1523 no other influential figure in the Reformation had yet achieved prominence.

Our approach departs from existing research on radical institutional diffusion generally and the Reformation specifically. Scholars of the Reformation have argued that the avaricious actions of the Roman Catholic Church placed numerous people on the "margin of defection," thus making them susceptible for adoption (Ekelund, Hébert, and Tollison 2002). Yet, this had been the case for centuries, leaving the "when" and "where" questions unanswered. A possible explanation is that the recent spread of the movable-type printing press (invented in 1450 in Mainz) helped reformers disseminate anti-papal propaganda before the Church could respond.[3] In support of this hypothesis, Rubin (2014) found that cities that were early adopters of printing were about 29 percentage points more likely to adopt Protestantism by 1600.

On the other hand, there is good reason to believe that the sole focus on printing has neglected relational processes that account for the Reformation's early breakthrough. The two-step opinion leader model of social diffusion suggests the success of a movement in the face of (probable and violent) resistance requires ideological innovations to be first taken up by resourceful, respected, and informed actors, who, in turn, increase the odds that others in their social circles will adopt as well (Rogers 2003; Valente 1996; Valente and Davis 1999; Watts and Dodds 2007). Lacking a core group of influential adopters from which the movement could spread, not enough individuals will adopt it to overcome the critical mass threshold, even if their private preferences are that the movement succeeds (Kim and Bearman 1997; Kuran 1995; Oliver 1993; Siegel 2009; Slater 2009).

Nevertheless, the relational diffusion paradigm runs into a substantive puzzle when applied to the Reformation. Behaviors that require significant costs to adopt, such as joining an insurgent movement or converting to a new religion, are predicted to spread across space from point of origin, neighbor by neighbor (Duling 2000; Everton 2018; Fousek et al. 2018; Hedström 1994; Stark 2006; Strang and Soule 1998). This is because sufficient persuasion is required to convince people to join, and spatial proximity creates channels of reinforcing ties to activate diffusion. For a movement to spread from one region to another implies that intervening locales need to adopt. However, contrary to this prediction, the early Reformation dispersed widely but unevenly across the HRE in scarcely more than a decade.

Furthermore, the Reformation did not spread spatially as a chain of cities, but rather as sparks that ignited across the length and breadth of Central Europe. Considering that Wittenberg was poor and isolated ("on the edge of civilization," in Luther's words), how could it have generated rapid spatial diffusion through urban networks? Luther's influence as communicated through personal ties may provide an answer. In our data, 36 percent of the towns that had any personal contact with Luther through the end of 1522 were Protestant by 1530, whereas only 6 percent of towns without any contact adopted the Reformation.

This striking pattern motivates our study. We show that contrary to the conventional explanation for the diffusion of the Reformation that relies almost entirely on the role of printing, Luther's entrepreneurship played a significant role. Luther's ideas gained institutional purchase in cities where he had personal ties. Furthermore, cities where Luther had personal influence often had trade relationships with one another, creating clusters of adopting cities, which, in turn, activated spatial diffusion (see Fousek et al. 2018:10). Neither Luther's personal ties nor spatial diffusion alone fully explains the spread of the early Reformation, but the *interdependent* combination of both does.

PERSONAL INFLUENCE AND STRUCTURAL REINFORCEMENT IN THE DIFFUSION OF RADICAL INNOVATIONS

Social scientists have long been interested in the mechanisms that explain the spread of behaviors, new ideas, and institutions (Christakis and Fowler 2007, 2008; Rogers 2003; Valente 2017; Watts 1999). What makes the diffusion of innovations of such profound sociological interest is that adoption is understood to be interdependent. The choice to adopt involves uncertainty and is shaped by social information, which influences the perception of the risks, costs, and benefits at stake. Adopting the innovation occurs, at least in part, because people assess their choices in light of other people's choices.

Some kinds of innovations take the form of fashions, fads, and passing trends, but others are radically transformative and enduring. Social scientists have studied the spread of new religious ideas and practices (Everton 2018), social movements (Givan, Roberts, and Soule 2010), and industrial revolutions (Becker, Hornung, and Woessmann 2011). In these cases, adoption, or "infection" in the language of contagion models, is followed by social action to consolidate or institutionalize the innovation.

Radical institutional innovation, of the kind championed by Luther and the Protestant movement, poses additional complications. In those instances, adoption of innovation is not simply a matter of buying the apocryphal "better mousetrap" but of accepting radical ideas that reject or upset the prevailing social order. When the innovation challenges vested interests or existing institutions, resistance is to be expected. Investment in the old and status quo bias may increase thresholds for embracing the new (Centola 2018; Centola and Macy 2007; Granovetter 1978; Kahneman, Knetsch, and Thaler 1991; Schelling 1978; Valente 1996). The resistance will be especially great where heterodox ideas compete against an incumbent orthodoxy (Kim and Pfaff 2012). In the face of high hurdles to adoption or resistance to change, why does an innovation spread?

Diffusion in a small-world setting suggests behavior spreads thanks to weak ties and long bridges that connect otherwise dispersed parts of a network (Watts 1999; Watts and Strogatz 1998). These weak ties expand the reach and efficiency of information flow, instigating the speed of diffusion. Nevertheless, although the argument that exposure induces adoption seems appealing, it may not be true in cases of high-risk behavior. Typically, when actors consider taking part in costly movements, they ask others to whom they are connected what they think, and evaluate information based on their responses. As Centola (2018:14) argues regarding the theory of

complex contagions, "The basic problem of diffusion—that is, the failure to spread behavior—occurs whenever behavior change encounters resistance. . . . The less familiar an innovation is, and the more inconvenient, uncomfortable, or expensive it is, the greater the resistance will be, and the less likely it will be to diffuse." The reason why such behaviors may not spread in viral fashion is that they require "legitimacy, credibility, or complementarity in order to be adopted" (Centola 2018:35).

Consequently, exposure to new information may be insufficient for some things to spread. If actors have to commit themselves to costly, dangerous, or uncertain undertakings, other incentives may be required. One explanation for how costly behavior spreads is broader social influence channeled through multiple and reinforcing ties—"wide bridges"—that induce an actor to adopt (Centola 2018; Centola and Macy 2007). When a mobilization effort is risky, its success "depends upon close-knit networks to establish trusted relationships and provide social reinforcement for participation" (Centola 2018:91). People do not need to be eager adopters to get swept up in a great upheaval. Structurally overlapping ties may create the social reinforcement to persuade even those who were initially resistant to join the movement.

Do the concepts of complex contagions and "wide bridges" explain the Reformation? In times where communication relied on roads and trade routes, spatially close neighbors would have been the most likely to share common ties, and hence costly behaviors are predicted to spread sequentially across space (Centola 2018; Strang and Soule 1998). For instance, in the case of the early Jesus movement and the spread of Christianity, dense social ties in the Galilee region appear to have facilitated the inception of the new religion, but subsequent diffusion across the Mediterranean world was largely driven by distance from Jerusalem (Duling 2000; Everton 2018; Fousek et al. 2018; Stark 2006). In the pre-modern world, the effective distance between places was determined by technological limitations and established trade routes, limiting the pace and reach of spatial diffusion (Brockman and Helbing 2013; Fousek et al. 2018). In spite of the plausibility of this understanding, the Reformation did not spread slowly outward from Wittenberg but instead was adopted across the breadth of Central Europe. Why?

The theory of complex contagions focuses on the overall structure of a network, and less on the characteristics of individuals in the network. However, certain individuals can become opinion leaders who promote the adoption of costly behaviors (Valente and Davis 1999; Valente and Pumpuang 2007; Watts and Dodds 2007). This means pressure exerted by especially influential people is more consequential than pressure from others. Their social exchanges make innovation contagious. Opinion leaders typically have more ties and greater tie diversity than do other individuals, but they may also have the human capital that makes their influence credible (Barabási 2009; Burt 2005; Manzo et al. 2018; Siegel 2009). The character of relationships matters as well. They do not need to be the highest status persons themselves, but typically they are resourceful, cosmopolitan, and strategic, making them open to exchange and communication with diverse partners, and linked with other resourceful and influential people (Rogers 2003).

Luther was this kind of person. As became evident by the time of the indulgence controversy in 1517 to 1518, Luther's correspondence, visits, and cultivation of a cadre of devoted students connected an ideological entrepreneur with a widely-dispersed set of local elites who otherwise would have lacked a tie to the Wittenberg movement.

THEORY AND HYPOTHESES

We propose a model of influence in which an innovator makes personal connections with dispersed elites, persuading them to adopt his innovation. They, in turn, influence others in their communities to adopt it as well, such that communities convert (see also Watts and Dodds 2007:441–2). Our understanding seems to correspond well with what we know about social relations in Luther's time. In

sixteenth-century Central Europe, theological issues like Luther's doctrine of justification and rejection of indulgences were, at least at first, only relevant to narrow circles of educated people. In a society in which literacy was limited to less than 10 percent of the population, many of Luther's correspondents—theologians, prominent burghers, humanists, nobles, and aristocrats—were well-suited to serving as conduits for the diffusion of Reformation ideas and their institutional adoption in the towns where they resided (Burt 2005:85–86; Manzo et al. 2018).

We do not contend that Luther's social network, which became extensive through his correspondence, visits to other cities, and cultivation of apostles among his students at Wittenberg, was initially designed to facilitate the spread of the Reformation. It originated before 1517, and the Reformation in its early days was an emerging and still incoherent movement. However, by the end of 1522, Luther's ties are indicative of the personal network of a movement leader, linking him to a diverse set of elites across the empire. As Roper (2010:294) observes of his letter writing, "Always carefully crafted and mostly written with an eye to a public beyond the ostensible correspondent, Luther's letters were strategic masterpieces." Such activities extended Luther's personal influence to dispersed circles of humanist intellectuals, theological dissidents, and reform-minded rulers.

The goal of this study is to examine the diffusion of the Reformation, so we examine whether Luther's ties to local elites contributed to its early breakthrough in the 1520s. However, we also take into account the possibility that instead of Luther's personal network, wide bridges emanating from Wittenberg connected people influenced by the Wittenberg movement, who, in turn, influenced structurally similar people to adopt the Reformation (Watts and Dodds 2007:442). First, we examine two simple influence hypotheses regarding the effect of Luther's personal network:

> *Hypothesis 1 (simple influence hypothesis I):* The personal influence of Luther upon a city prior to 1523, as proxied by the presence of correspondents, visits, and students, increased the probability that the city adopted the Reformation by 1530.

However, the implications of diffusion models of costly behavior suggest *multiple* interpersonal interactions between Luther and local elites in a city would have facilitated the diffusion of the Reformation. This could come through Luther either having multiple correspondences with the same person or having contact with multiple people (either of which we call an "interaction"). We therefore might expect Luther's influence furthered the adoption of Protestantism to the extent that he had multiple interactions with people in a town:

> *Hypothesis 2 (simple influence hypothesis II)*: The greater the number of interactions Luther had in a given city prior to 1523, the higher the probability the city adopted the Reformation by 1530.

Luther's personal influence was not the only social mechanism through which the diffusion of the Reformation could have occurred. If diffusion does not require connections with influential leaders at all, but rather occurs virally through contact with similar others (Watts and Dodds 2007:442), spatial diffusion is another candidate for explaining the spread of Protestantism. In early modern Europe, the flow of people, goods, and information occurred chiefly through channels of trade, making merchants diffusion vectors (Wurpts, Corcoran, and Pfaff 2018). We would expect cities that adopted Protestantism to influence adjacent others via trade routes and thereby contribute to the spatial diffusion of the Reformation. Moreover, if multiple cities in a network neighborhood adopted Protestantism, it would have reduced the uncertainty surrounding adoption and its expected costs. Based on threshold theories of adoption (Centola 2018; Centola and Macy 2007; Granovetter 1978; Schelling 1978; Valente 1996), we expect that adoption by any given city would be

conditional on multiple neighboring cities having adopted. We therefore propose spatial diffusion as an alternative to diffusion through an opinion leader:

> *Hypothesis 3 (alternative hypothesis):* The spread of the Reformation followed a spatial pattern along contemporaneous trade routes via the mechanism of multiple exposure.

Finally, Luther's influence networks and spatial diffusion may be *complementary mechanisms*. Let us draw an analogy to the spread of an extensive fire. Forest fires of the kind that have ravaged the American West and Australia do not require some trees to be more influential than are others. Fires spread because trees are proximate to other burning trees (Biggs 2005). Nevertheless, special conditions can accelerate the spread of the fire. For instance, winds pick up sparks and distribute them far from the edge of the blaze, setting off new fires when the embers fall on dry woods.

The diffusion of innovations may be similar. Luther's influence spread outward from Wittenberg across the region of Electoral Saxony, but it also cast sparks across Central Europe, stirring local elites to set fire to the Roman Church. Our model of social influence is consistent with a complementary process whereby Luther converted cities that did not adjoin Wittenberg through direct social influence, which, in turn, further spread the Reformation by seeding clusters of adoption that could trigger subsequent diffusion. The success of the early Reformation may thus have relied on a combination of the dispersion of Luther's personal influence through personal network ties and spatial diffusion via trade routes:

> *Hypothesis 4 (interdependency hypothesis):* The spread of the Reformation was an interdependent combination of Luther's personal influence and spatial diffusion.

We use cities as our level of analysis, as they are meaningful adopters (Palloni 2001), particularly in the context of early modern Central Europe where they had substantial autonomy, including the governance of religious affairs. Hypotheses 1 and 2 aim to establish Luther's network effect, which we test via regression analysis. Hypotheses 3 and 4 involve interdependent diffusion through networks, which we explore through dynamic network simulation.

THE CONTEXT: ORIGINS OF THE REFORMATION

Luther was an Augustinian friar and professor of Biblical theology. Beginning in the 1510s, his studies led him toward increasingly critical positions. From 1517 onward, Luther attacked the Roman Church and made Wittenberg the theological and organizational center of a reform movement. In the remarkable period through 1522, Luther embarked upon three lines of attack against the Church's seemingly incontestable position. First, he cast doubt on the veracity and efficacy of its doctrines of justification and penance. Second, he assailed the holiness of the Church, criticizing the papacy, monasticism, and the sacramental role of the priesthood. Finally, he offered a rival set of doctrines and practices that would become the ideas and institutions that gave birth to new Protestant churches (Goldman and Pfaff 2017:71–94).

Within a decade of Luther's posting of the *Ninety-Five Theses* in 1517, many towns across the HRE adopted the reforms he advocated (Dittmar and Meisenzahl 2020). Unlike previous theological dissidents whose reform movements were contained by defenders of the status quo, by 1530 about 10 percent of German cities were already Protestant, a share that would expand much further after that point (Rubin 2014).

Historians have shown that the main thrust of the popular movement that propelled Protestantism took place in towns and cities in the 1520s (for a review, see Becker et al. 2016). In this early phase, the Protestant challenge generated urban political coalitions that propelled reform (te Brake 1998:35–44). These coalitions challenged the local political and

religious establishment, pressuring local elites to institute a new religious regime. Several incentives for reform helped motivate the formation of Protestant coalitions. Many burghers saw the Reformation as a chance to improve urban governance, eliminate privileges and tax exemptions favoring monasteries and the clergy, unify the legal code, and challenge the dominance of patrician interests in city councils. Likewise, outside the cities, some princes saw Luther's movement as a long-desired opportunity to reduce the Church's influence in local economic and political affairs (Rubin 2017).

Religious contention assumed different forms in different cities but resulted either in the institution of reform or in the defeat of the movement. Whereas traditional historiography selected cases in which the Reformation prevailed (Scribner 1986:26), less attention has been given to cases in which "popular support for religious reform remained scattered and the cooperation between reforming preachers and responsive laity was too fleeting" (te Brake 1998:39). What made for cohesive and determined Protestant coalitions that could prevail in a city? Luther's ties to local elites seem to have been one factor (Kim and Pfaff 2012).

The following example illustrates how Luther's personal influence could have fostered local adoption. The towns of Überlingen and Konstanz (Constance) are neighbors in the southwest corner of Germany, about 400 miles from Wittenberg. In terms of the factors that are expected to influence adoption, the two towns were very similar, with Überlingen perhaps more prone to adoption. They are eight miles apart as the bee flies, separated by Lake Constance, with Konstanz on the far southern side of the lake, further away from Wittenberg, so less likely to be exposed to Luther's ideas by word of mouth. Neither of the towns had a printing press in 1500; both were imperial cities, free from the rule of a local prince; neither were Hanseatic cities; and they were of similar size (Konstanz had around 4,000 inhabitants, and Überlingen around 3,000) (Bairoch, Batou, and Chèvre 1988). Furthermore, Konstanz was a Catholic bishopric, which should have worked *against* adoption of the Reformation. Luther visited neither city, but Konstanz had two letter exchanges with Luther before 1523, and Überlingen had none. Whereas Konstanz enrolled five students at Wittenberg after Luther began his attacks on the Church in 1517, Überlingen enrolled none. One of these students, Thomas Blarer, enrolled at Wittenberg in 1520 and studied with Luther, even taking part in the public burning of the papal bull that excommunicated Luther. In 1523, he returned to Konstanz where he joined a circle of active reformers and won election to the city council in 1525. Konstanz adopted the Reformation in 1527, driving the Catholic bishop out of the city. Überlingen had no such activist cadre, publicly burned Luther's works in 1521, arrested visiting Lutheran preachers, and remained Catholic.[4]

Other explanations have been proposed, but recall that, at the global level, the early Protestant movement was neither cohesive nor well-coordinated. Moreover, early in the Reformation, the will of the princes played a small role in pressuring cities to reform (Dixon 2000). It was not until a Protestant alliance declared itself to the Imperial Diet, which met at Augsburg in 1530, that the Reformation attained cohesion and clear political backing.[5] If not through formal organization or the work of the princes, how did the Reformation achieve its early breakthrough? The previous literature suggests several reasons. Ekelund, Hébert, and Tollison (2002, 2006) argue that individuals throughout late-medieval Europe who "demanded" spiritual services were placed on the margin of defection by the Church's increasingly avaricious and monopolistic practices. In such a setting, rival "firms" had an opportunity to enter the religious marketplace by offering a less costly path to salvation. The Protestant movement took advantage of this opportunity in the spiritual marketplace, offering a substitute that was highly desired by large swaths of the population.

Yet, theories that claim a new religion was in high demand leave much unexplained. The phenomena described by Ekelund and

colleagues (2002, 2006)—a monopolistic Church engaged in increasingly worldly pursuits—existed for centuries prior to the Reformation. Indeed, such practices were among the chief complaints of previous attempts at reform. Peter Waldo's (1140–1205) reform movement, Jean Gerson's (1362–1429) conciliarism movement, Wyclif's (d. 1384) Lollard movement, and Hus's (c. 1372–1415) Bohemian rebellion all put forth grievances similar to those that would propel Luther's movement in the 1520s (Rubin 2017:130–31). All were crushed or survived only as isolated sects. On the other hand, two features of the spread of the Reformation can help account for its timing and location: the spread of the moveable-type printing press and the tireless efforts of Martin Luther. His social influence helped the Protestant movement gain a strong footing in the 1520s, the period before princes and nobles assumed a leading role.

Persuasion was vital to the spread of Protestantism (Pettegree 2005). Luther adeptly exploited the medium of printing to reach literate people. He published tirelessly and his output of theological works and vernacular pamphlets in the decade after 1517 was prodigious. An influential translation of the New Testament from Greek into colloquial German appeared in 1522. By the time of the Augsburg Confession in 1530, his works had been widely circulated and reprinted by presses across the HRE and beyond (Edwards 1994; Eisenstein 1979; Pettegree 2015).

Luther declared that printing made his mission to spread the "true religion" possible (Holborn 1942), and historians generally agree. Edwards (1994:1) observes that "the Reformation saw the first major, self-conscious attempt to use the recently invented printing press to shape and channel a mass movement." Brecht (1985:208–9) asserts that "[w]ithout the new medium of the printing press Luther's thoughts would never have achieved such a rapid and wide distribution." Luther intuitively understood the print business and he knew how to exploit it (Pettegree 2015; Roper 2017). No wonder Moeller (1979) pronounced simply, "No printing, no Reformation." Recent studies by economic historians provide compelling evidence supporting the causal role that printing played in the spread of Protestantism in the century after 1517 (Boerner, Rubin, and Severgnini 2019; Dittmar and Seabold forthcoming; Rubin 2014). Nevertheless, although Luther's printed works quickly reached every part of Central Europe, there was substantial spatial variation in early adoption of the Reformation that our results will show printing cannot explain.

Previous studies have not measured Luther's influence using network analysis. Other studies delineate various pathways, such as spatial neighbors (Cantoni 2012) or involvement in the Hanseatic trading league (Wurpts et al. 2018), by which the Reformation could have spread, but our concern is to examine how a framework of multiplex networks with multiple diffusion can explain the impact of the leader on the spread of an insurgent movement.

RELATIONAL BASES OF DIFFUSION: WHAT LUTHER'S TIES REVEAL ABOUT SOCIAL INFLUENCE

From a structural perspective on network diffusion, Luther's influence is perplexing. If behaviors that incur significant cost, like converting to a heterodox ideology, require reinforcement from multiple sources (Centola and Macy 2007; Granovetter 1978; Manzo et al. 2018; Schelling 1978; Valente 1996), Luther was only *a single source of contact* that nevertheless appears to have increased the odds of adoption. We are persuaded that the relational basis of network ties can affect the probability of diffusion (Erikson 2013; Valente 2017), and that leads us to inquire: Why was Luther so infectious?

Luther used three means to exert influence besides printing. First, Luther crafted a wide-ranging, diverse correspondence. Second, he visited cities where he made friends and acquaintances and gave sermons or attended public disputations related to theological

controversies. Third, he cultivated students at Wittenberg to become advocates of his reforms, urging them to return to and redeem their hometowns. Together, these sets of relations allowed Luther to make personal connections with local elites in widely dispersed towns. In our dataset, our measures of Luther's contacts predate the year 1523, when the Protestant reforms were first formally adopted. In other words, the network measures precede the diffusion of the Reformation to avoid reverse causation.

Luther's correspondence reveals the relational work that helped spread Protestant adoption. He was a prolific and wide-ranging correspondent. He used letters to establish and shore up the "vivid friendships" that sustained him and gave the Reformation its first foothold in Wittenberg. Letters to a wider circle of friends and supporters beyond Wittenberg helped propel a movement in which Luther was the central figure (Brecht 1985; Roper 2010:283, 2017:xxiii).

The data analyzed for this article include 234 letters written between 1501 and 1522. We deliberately exclude letters sent within Wittenberg and Erfurt, Luther's two places of residence, for which there are 274 and 50 letters, respectively. Of the 234 letters, 152 were sent by Luther and 82 were received by Luther. It may be surprising that so much correspondence was exchanged in sixteenth-century Europe. However, a postal system had evolved that made sending and receiving letters reliable and inexpensive (Greengrass 2016). Enabled by it, a lively culture of intellectual exchange thrived among the small, but growing, literate minority dispersed across the cities and university towns of Central Europe. Humanists reimagined the letter as something more than an instrumental exchange. Letters were ways to construct relationships and conduct conversations between absent friends, including among correspondents who never met in person (McLean 2007). Humanists knew that letters were semi-private and that they were frequently read aloud in company and passed along to others. In the case of Luther and other famous people, letters might be collected and printed for a wider readership (Greengrass 2016; Roper 2010).

Luther was a "brilliant, engaging correspondent" (Roper 2017:xxxiii). He used letters to stay in contact with students and colleagues, rally supporters, address theologians and critics, answer requests for assistance or advice, and persuade powerful people like princes and city councilors to adopt reform (Brecht 1985:77–80; Greengrass 2016; Roper 2010, 2017). In short, Luther was well steeped in the art of humanist letter writing (Greengrass 2016; McLean 2007).

We do not have full information about Luther's ego network, but we can gain a glimpse through the full sample of his collected letters (Perry, Pescosolido, and Borgatti 2018). Through the end of 1522, his correspondents comprised 129 distinct alters. Luther's network was remarkably diverse. Despite the fact that Luther spent the majority of his career through 1522 as a monk and professor at a provincial university, his correspondents included not only theologians and priests, but also nobles, higher ecclesiastical officials, state officials, and a few prominent burghers. Not surprisingly, his correspondence network was denser around his residence and intellectual home, as evidenced by the many letters written to correspondents in his own city of Wittenberg. Nevertheless, Luther's network suggests moderate cosmopolitanism, with a mixture of strong ties to friends, collaborators, and Wittenberg colleagues, and weak ties that linked him to correspondents in other cities. This structure, combining densely-knit and intimate "provincial" ties with dispersed and diverse ties (even to people in far-off cities) is precisely the kind of moderately-cohesive network considered favorable for the spread of religious movements across times and places (Centola 2015; Everton 2018:67–8; Stark 1996).[6]

Given Luther's diverse contacts, from a structural perspective it is likely they also crossed geographic lines. We examine this possibility by mapping the cities that received Luther's letters in Figure 2. Figure 2 reveals

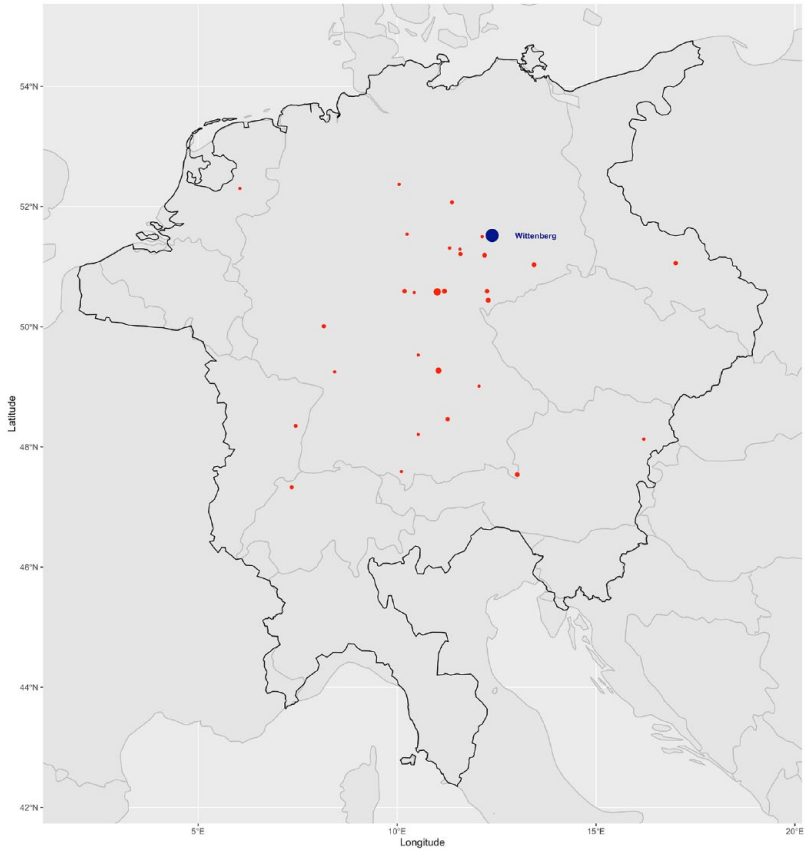

Figure 2. Map of Cities to Which Luther Sent a Letter, 1501 to 1522
Note: The black outline is the boundary of the HRE in 1548. Dot size corresponds to the number of letters sent by Luther. HRE outline from https://worldmap.harvard.edu/data/geonode:holyromanempire_551.

key spatial aspects of Luther's correspondence network. Although Luther was most frequently in contact with residents in or near Wittenberg, he was also in contact with people in cities that were spatially distant. Luther was not only in contact with places that already supported him. Some cities that feature prominently in Luther's correspondence, such as Leipzig and Mainz, were centers of opposition to the early Reformation. The inferences we can draw about the influence of Luther's letters is not constrained by the possibility that he wrote only to people who were his close friends or were already convinced by his ideas. Luther's long-distance correspondents included many who were straddling the fence, were skeptics, or were even outright antagonists. Naturally, he did not persuade everyone.

Other features of Luther's correspondence provide qualitative insight into why he was socially influential. Luther's investment in the social capital necessary to sustain his movement is discernible. In his early career, no correspondent was more prominent than was George Spalatin, a university official, state secretary, and advisor to Prince-Elector Frederick of Saxony, to whom Luther sent about 44 percent of all letters (including those written within Wittenberg). Spalatin served "as the middleman between his prince and Luther, gently guiding Frederick into policies that protected and supported the reforms that his professor and colleagues were promoting" (Kolb

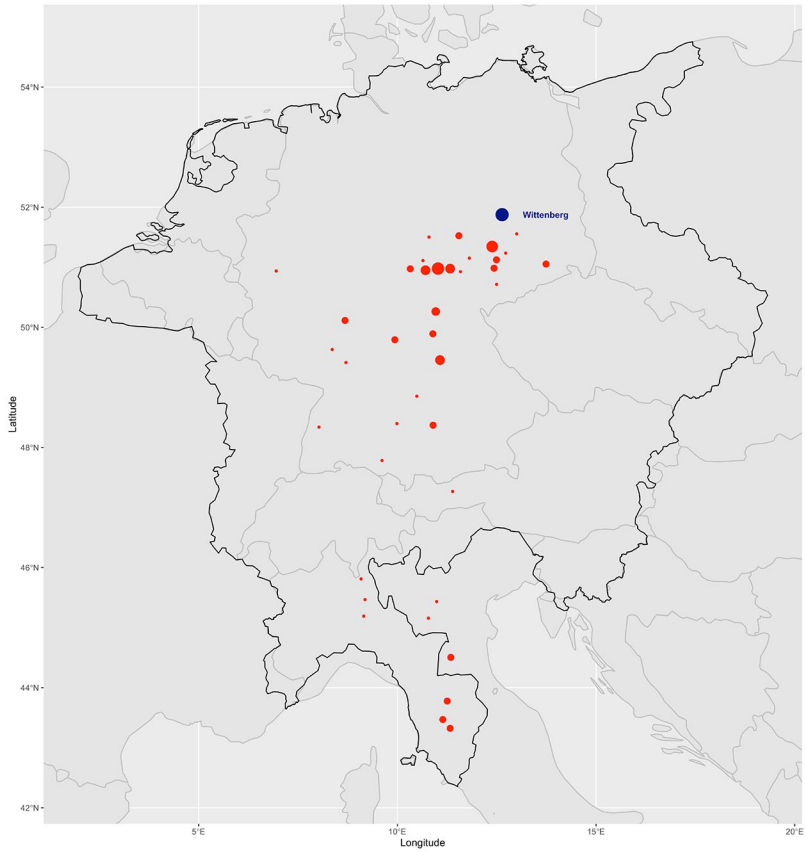

Figure 3. Map of Luther's Visits

2018:59; see also Roper 2010). Although Luther sometimes wrote to the prince directly, communication was usually mediated through Spalatin, as the prince was wary of being seen as a friend to the renegade. Spalatin ensured Luther could remake the university according to his reformed vision and enjoy the prince's patronage and protection.

The language used in Luther's correspondence is also telling. Fully 81 percent of letters written by Luther are in Latin. Luther addressed priests, academics, and individuals with humanist educations in Latin. He wrote letters in German only to "laymen"—nobles and burghers who were not members of the clergy and had not studied at universities. Even though there were few of these letters, they were important. Writing letters in German to Frederick and other nobles was a good strategy for Luther. It allowed him to address them directly, instead of through their secretaries. This created personal sympathy but it was also a powerful statement in itself. Corresponding in German reduced the spiritual status difference between a cleric and a layman, an important principle of Luther's new theology, which sought to abolish the priesthood and rejected the ontological superiority of the Catholic vocations. In this, he was practicing a radical innovation because, according to orthodox norms, priests were not supposed to engage in theological discussion with laypeople or conduct these discussions in vernacular languages.

In addition, Luther also made several journeys that allowed him to make contacts and influence local elites. As Figure 3 reveals, many of the destinations reached by Luther on his journeys were in relative proximity to Wittenberg. However, he also undertook

several journeys outside his native region of Saxony. Some were occasioned by his studies or the business of his monastic order, including a journey to Rome. Others arose in connection with the theological controversies Luther entered, including academic disputations in Heidelberg and Leipzig. A few resulted from appearances before papal officials or the Imperial Diet, as in his journeys to Augsburg and Worms.

The journeys provided Luther with abundant opportunities to make personal connections and win friends and allies. In most of the cities he visited, Luther enjoyed the hospitality of either local notables or a monastic community. In about half the places Luther visited, he preached, gave a public address, or met senior political or ecclesiastical officials (Buchwald 1929). The detailed accounts of his journeys in Köhler (1880) and Lingke (1769) reveal how Luther used visits as opportunities to widen his social network and cultivate allies.[7]

Although visits were probably one of the most effective ways by which Luther could influence local opinion and forge alliances, he could not travel as he wished. Through the end of 1522, Luther was a friar, subject to monastic rules, and living within the confines of the cloister and the university. Furthermore, Charles V's Edict of Worms in 1521 forbade anyone to receive Luther and promised a generous reward for his capture. Henceforth, Luther was effectively denied extra-local travel.

Although Luther could not travel as widely as may have been advantageous, with the inception of the indulgence controversy in 1517, Luther began to mobilize students to become apostles of the Protestant cause. Luther saw the Reformation as a missionary enterprise and Wittenberg as its cradle (Grendler 2004; Schwiebert 1996). Writing to Phillip Melanchthon, Luther evoked biblical imagery: "[Y]ou lecture; Amsdorf lectures; Jonas will lecture; do you want the kingdom of God to be proclaimed only in your town? Do not others need the gospel? Will your Antioch [Wittenberg] not release a Silas or a Paul or a Barnabas for some other work of the spirit?" (Hendrix 2010:25). Kim and Pfaff (2012) show that Luther cultivated a cadre of students with the intention of sending them back to their native towns to preach and agitate for the Reformation. By analyzing their sermons, Moeller (1999) documents a remarkable degree of Wittenberg party spirit among the first generation of Lutheran preachers. Not only were they strongly partisan but they evidenced remarkable doctrinal fidelity to Luther's theology. As Figure 4 shows, Luther's students allowed him to project his influence widely, connecting him with areas of the empire he never had the chance to visit and in which he had few personal connections through correspondence.

In short, Luther can be understood as "hyper-influential." He wrote tirelessly, visited influential people when possible, sent students to foster connections, established alliances with nobles and princes to enhance his legitimacy, and wrote in German or Latin according to the recipient. Structurally, these efforts suggest Luther spent excessive energy in fostering each tie. However, relationally, they suggest each tie was strongly rooted, which provided the basis for Luther's infectiousness.

Although some cities had multiple ties to Luther, most of the cities during our period of study had only a single contact with Luther: either correspondence, a visit, or students. However, these ties may help explain why, in both spatial and social terms, the reach of Luther's movement was surprisingly extensive. These ties allowed Luther's influence to extend beyond the confines of "Lutherland"—Wittenberg and nearby places—shedding sparks on dispersed locations, a factor that may have been decisive in increasing the pace of diffusion.

How could the sparks shed by Luther trigger Protestant movements in places distant from Wittenberg? Abundant historical evidence suggests Luther's reach extended outward through trade-route ties to cities he had influenced. Trade routes carried not only goods but people and ideas. Itinerant preachers and evangelical theologians fanned out from emerging Protestant centers, often preaching in fields and city squares when church authorities forbade them entry (Hannemann 1975).

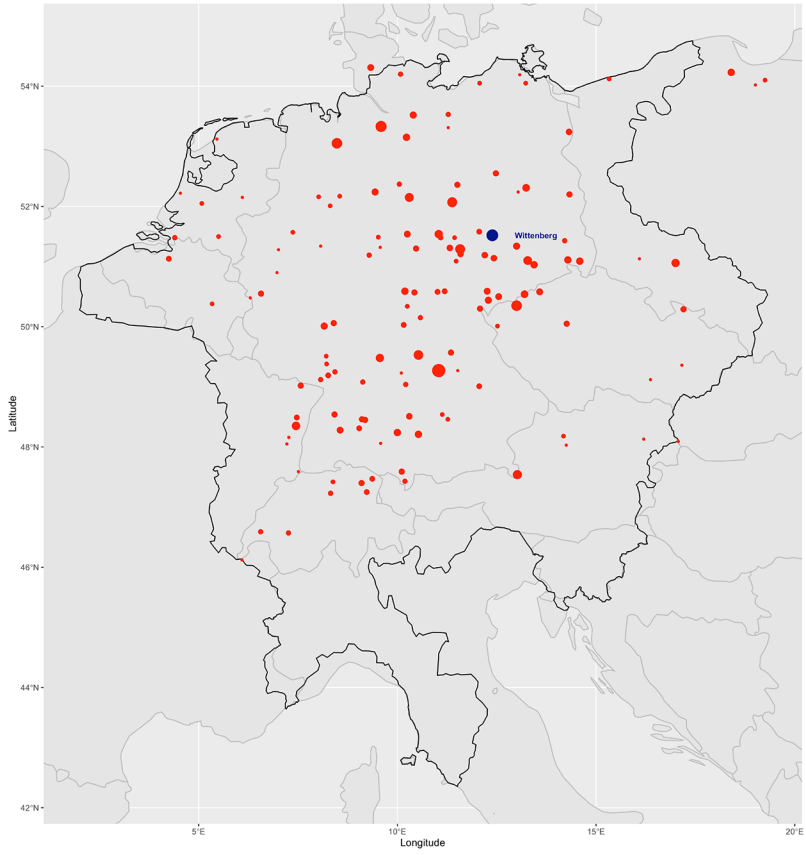

Figure 4. Map of Location of Luther's Students, 1517 to 1522

Luther's gripping pamphlets and translation of the New Testament were carried in traders' wagons and in the holds of ships, connecting cities with presses to those without (Edwards 1994). Merchants persuaded by Luther's message shared their opinion with colleagues and business associates (Wurpts et al. 2018).

For example, Ribe in Southern Denmark, close to the Duchy of Schleswig, had no personal connections to Luther but had trade route connections to cities including Husum and Hamburg that had them. Husum sent Wittenberg-trained preachers to Ribe who helped foster its adoption of the Reformation (Grell 2000:260–64). In Oldenburg, which also had no local ties to Luther, ties to Bremen, the city's major trading partner, boosted reformers. In 1528, a Wittenberg-trained theologian arrived from Bremen to direct the campaign against Oldenburg's conservative establishment and well-entrenched monasteries. Soon after, the council abolished the Catholic mass (Förster 2019:37–43). Winterthur had no connections to Luther but had many ties to the emerging Protestant movement through trade routes linking it to Schaffhausen, St. Gallen, and Konstanz. The Zwinglian reforms in nearby Zürich, its major trading partner, also made a powerful impression on the town council (Niederhäuser 2020).

DATA AND QUANTITATIVE EVIDENCE FOR THE LUTHER EFFECT

To examine the connection between Luther's network and the spread of the Reformation, we use several data sources. Our universe of observations in the regression analysis is cities in the de jure HRE that are part of the dataset collected by Bairoch and colleagues

(1988).[8] We exclude Wittenberg and Erfurt, Luther's two places of residence, in all analyses.[9] This leaves us with 300 cities with population data in 1500. Data on Reformation adoption, printing press adoption, and a host of control variables are from Rubin (2014).

We measure Luther's personal influence through two novel sources of data: his correspondence and the towns he visited. Additionally, we measure Luther's influence through enrollments at Wittenberg during the key years 1517 to 1522.[10] We also include a control for Luther's indirect influence through the printing of books and pamphlets.

Luther's Correspondence

The data coded from Luther's collected correspondence reveals an *ego-centered* network (Perry et al. 2018). It is ego-centered because it is based on Luther's correspondence with others and not on ties between alters in his network (i.e., it is not a "friends of friends" network). Our work exploring Luther's letters as a way to learn about his network follows in the footsteps of others who have, for instance, constructed ego-centered networks of letter writers in the early periods of Christianity (Mullett 1997; Schor 2011) and the Medici (Molho 1979). We go beyond this work insofar as we use it to explore the spread of ideas in regression analyses and network simulations. Although potential incompleteness in the data could bias our understanding of Luther's ties to other places, historians suggest the corpus of letters sent by Luther is nearly complete (Brecht 1985; Greengrass 2016; Roper 2010, 2017). Substantively, the exchange of letters in humanist culture was guided by a strong norm of reciprocity among correspondents, meaning Luther's outgoing correspondence included replies sent to those from whom he received letters even if he had not initiated the exchange or saved the letter.[11]

Luther's correspondence is coded from the recently digitized Weimar edition of Luther's collected works (*Luthers Werke* 2018). Each entry contains the addressee and the date of the letter. From these we coded several variables. For the primary analysis, we focus on outgoing letters (i.e., letters written by Luther). We do this because letters written to Luther do not necessarily reveal an influential tie to Luther: they could simply be "hate mail" or "fan mail." We focus on letters Luther sent to recipients outside Wittenberg and Erfurt, his two places of residence between 1501 (year of first letter) and 1522. There are 152 outgoing letters, but also 82 incoming letters, that is, 65 percent of the surviving letters with correspondents outside Wittenberg and Erfurt are outgoing and 35 percent are incoming. In the regression analysis, our main specifications use only outgoing letters, but robustness checks in Table S4 in the online supplement show results when counting both outgoing and incoming letters.

We coded (1) a "Luther letter by end of 1522" dummy, and (2) the "number of Luther letters by end of 1522." Moreover, we know whether letters are in Latin or German, which reflects the audience to which Luther was appealing. Results breaking down letters by the language in which they were written are reported in Table S5 in the online supplement.

Luther's Travels

To capture a second channel of social influence that may have been operating besides Luther's correspondence, we coded the location of all towns Luther visited in the course of his career through the end of 1522. These data are recorded in the *Luther-Kalendarium*, an exhaustive register of all of Luther's known activities (Buchwald 1929).[12] As in the case of Luther's letters, we code both a binary variable (whether Luther visited a town prior to the end of 1522) and a count variable (the number of times he visited a town prior to the end of 1522).

Luther's Students

Third, we measure the number of students who enrolled at Wittenberg University from a given town during the period from 1512, when Luther assumed his professorship,

Table 1. Summary Statistics

Variable	Mean	Standard Deviation
Dependent Variable		
Protestant in 1530	.19	.02
Primary Independent Variables		
Binary Variables		
Luther letter by 1522 dummy	.09	.02
Luther letter in Latin dummy	.08	.02
Luther letter in German dummy	.04	.01
Luther visit by 1522 dummy	.11	.02
Luther students (1517–22) dummy	.41	.03
Any connection to Luther dummy	.45	.03
Count Variables		
Number of Luther letters by 1522	.39	.11
Number of Luther letters in Latin by 1522	.29	.09
Number of Luther letters in German by 1522	.07	.03
Number of Luther visits by 1522	.19	.04
Number of Luther students (1517–22)	2.41	.30
Control Variables		
Printing press by 1500	.29	.03
Luther printed works dummy	.11	.02
Number of Luther printed works (/100)	.03	.01
Log of population in 1500 (1000s)	1.68	.05
Independent city dummy	.14	.02
University by 1450 dummy	.04	.01
Bishopric by 1517 dummy	.19	.02
Lay magnate dummy	.77	.02
Market potential in 1500	14.34	.19
Water dummy	.74	.03
Hanseatic dummy	.18	.02
Latitude	50.13	.13
Longitude	8.70	.21
Log distance to Wittenberg (km)	5.91	.04
Log distance to Zürich (km)	5.94	.04

Note: Only cities in the de jure HRE and for which population data exist are included. Wittenberg and Erfurt, Luther's two places of residence, are not included. $N = 300$.

through the end of 1522. The data were coded from the Wittenberg matriculation book edited by Förstemann (1841). In the primary analysis, we focus on students who came to Wittenberg after Luther posted the *Ninety-Five Theses* (i.e., 1517 to 1522). In Table S4 in the online supplement, we report regressions in which we only look at students who enrolled prior to 1517 (i.e., 1512 to 1516) and over the entire period under study (1512 to 1522). We code both a binary variable (whether there was a Luther student from the town) and a count variable (the number of Luther students from a town). Table 1 shows summary statistics of variables.

We also construct variables derived from principal component analyses of our three primary Luther dummy variables (Luther letter, Luther visit, and Luther students) and another set of variables from principal component analyses of our three primary Luther network count variables. In all regressions using these variables, we only include the first principal component.[13]

Figure 5 reports this breakdown of the raw data. It suggests a relationship between the

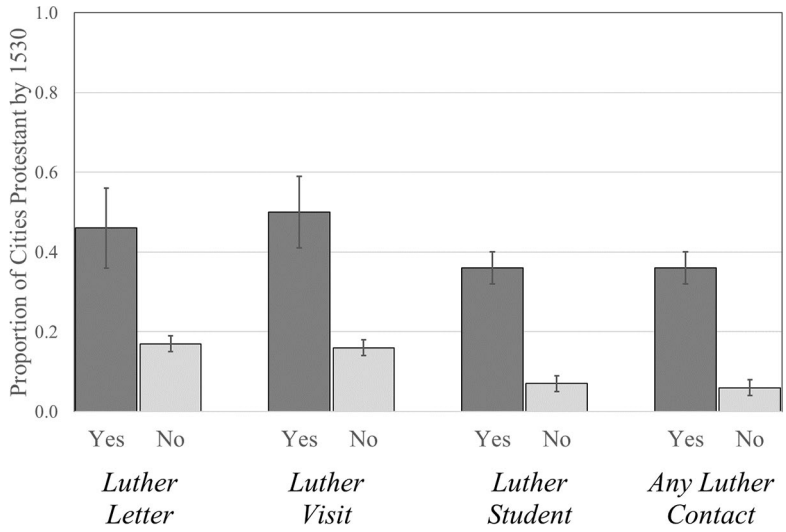

Figure 5. Proportion of Cities that Adopted Protestantism by 1530, by Various Characteristics

spread of the Reformation and the various Luther network variables. Of the towns that had people who corresponded via letter with Luther by 1522, 46 percent were Protestant by 1530. Of the towns that contained no one who corresponded with Luther, only 17 percent were Protestant by 1530. A similar relationship obtains with respect to Luther's visits. Of the towns he visited (did not visit), 50 percent (16 percent not) were Protestant by 1530. A similar pattern holds with respect to towns from which students at Wittenberg resided. Among towns that sent students to Wittenberg, 38 percent adopted the Reformation by 1530, whereas only 7 percent of towns that did not send students were early adopters of the Reformation. Of the towns Luther had any contact with (via letter, visit, or student), 36 percent adopted the Reformation by 1530, and only 6 percent of towns he had no contact with did so.

ESTIMATING THE ASSOCIATION BETWEEN LUTHER'S NETWORK AND PROTESTANT ADOPTION

To evaluate whether social ties to Luther affected the diffusion of the early Reformation, we code the various measures from Luther's network up to the end of 1522. Our focus is the early Reformation. We therefore estimate probit models predicting the probability of adopting Protestantism by 1530.[14] The dependent variable is coded 1 for cities that are Protestant in 1530 and 0 otherwise.[15] The focal covariates are the Luther network variables.

The main reason we use a regression analysis to examine the effects of Luther's network on the Reformation is that many socioeconomic features may (spuriously) affect both. Fortunately, many of these features are either observable or there are observable proxies for them. For instance, the education and literacy rate of a town is likely related to Luther's network, since Luther ran in an educated circle, and it may have had an independent effect on the propensity to adopt the Reformation. Although we do not have literacy rates from this period, two useful proxies are the presence of a printing press and a university. Likewise, penetration of the Church in a town likely affected the likelihood of both it being part of Luther's network and it adopting the Reformation. Hence, it is useful to control for whether the town was the seat of a bishopric, a proxy for Church influence.

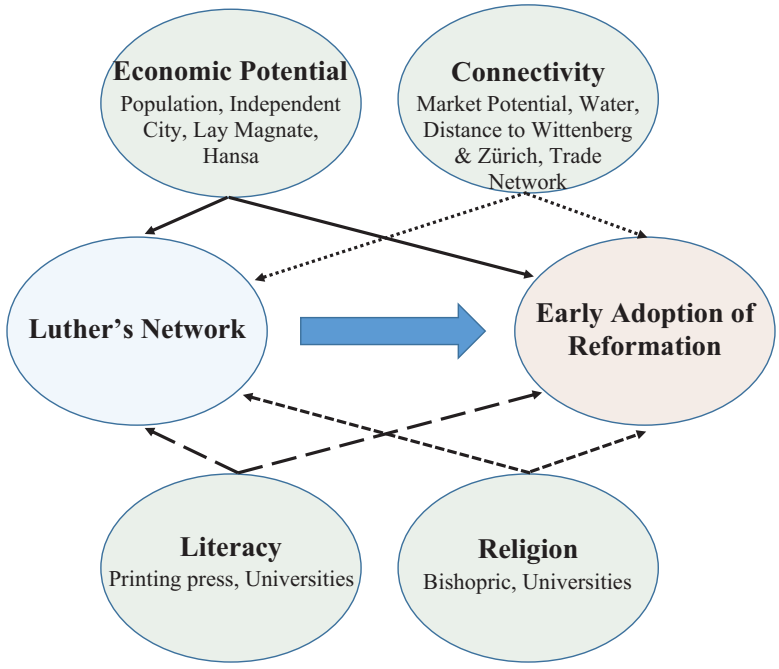

Figure 6. Possible Confounders in the Regression Analysis

Two other features of towns may have affected both the propensity to be part of Luther's network and the propensity to adopt the Reformation: a town's economic potential and its connectivity to other towns. Fortunately, we have numerous proxies for both. Regarding economic potential, we can adjust for whether the city was independent, ruled by a lay magnate, and was part of the Hanseatic trading guild. With respect to connectivity, we can control for the city's market potential, whether it was on water, its distance to Wittenberg and Zürich (the homes of Luther and Zwingli), its position in the trade network, and its latitude and longitude.[16] For a summary of these potentially confounding variables, see Figure 6.[17]

We therefore specify the following regressions models, for each city i:[18]

$$\text{Prob}\left(\text{city Protestant by } 1530_i\right) = \beta_0 + \beta_1 \text{Luther\_Network}_i + \boldsymbol{\beta}\mathbf{X}_i + \varepsilon_i, \quad (1)$$

where Luther_Network_i is one of the various measures of Luther's network noted above, and $\mathbf{X}_i$ is a vector of controls. Each of the reported regressions uses a probit specification.

Table 2 reports marginal effects on the coefficients presented in Equation 1.[19] Supporting Hypothesis 1, we find that the ties revealed by Luther's correspondence are positively associated with adoption of the early Reformation. Results reported in column 1 indicate that cities Luther corresponded with were 13.6 percentage points more likely than other cities to adopt the Reformation by 1530, all else being equal ($p < .05$). This supports our proposition that personal ties linking the Wittenberg movement through Luther to a town would increase the probability the town would adopt the Reformation by 1530.

The results reported in column 2 support Hypothesis 2. They indicate that each letter Luther sent is associated with a 2.7 percentage-point greater probability of a town adopting the Reformation by 1530 ($p < .01$). This is not a trivial point estimate: of the 29 towns that received a Luther letter prior to 1523 (excluding Wittenberg and Erfurt), 16

Table 2. Determinants of Reformation Adoption by 1530

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Dependent Variable: Protestant by 1530								
Luther letter dummy	.136*								
	(.063)								
Number of Luther letters		.027**							
		(.008)							
Luther visit by 1522 dummy			.186**						
			(.068)						
Number of Luther visits				.090**					
				(.029)					
Luther students dummy					.097*				
					(.043)				
Number of Luther students						.007**			
						(.003)			
Any connection to Luther dummy							.124*		
							(.051)		
First principal component of Luther variables (dichotomous)								.060**	
								(.015)	
First principal component of Luther variables (count)									.054**
									(.016)
City-level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	300	300	300	300	300	300	300	300	300
No. of clusters	138	138	138	138	138	138	138	138	138
Pseudo R-squared	.363	.369	.385	.384	.360	.354	.367	.401	.390

Note: Robust standard errors clustered by territory are in parentheses. Average marginal effects of probit coefficients reports for all regressions. City-level controls include dummies for the printing press, whether a city printed a work by Luther (in columns 1, 3, 5, 7, and 8), the number of printed works by Luther (in columns 2, 4, 6, and 9), independent city, university, bishop, lay magnate, on water, Hanseatic league, log of population in 1500, market potential in 1500, log distance to Wittenberg, log distance to Zürich, latitude, longitude, and the interaction of the city's coordinates. All regressions include a constant term (not reported). Distance to Wittenberg and Zürich are in km. Wittenberg and Erfurt, Luther's two places of residence, are not included.
$^{*}p < .05$; $^{**}p < .01$ (two-tailed tests).

received at least two letters and 10 received at least five letters.[20]

Results in column 3 indicate that towns Luther visited were 18.6 percentage points more likely to adopt the Reformation by 1530, all else being equal ($p < .01$), and results in column 4 suggest that every Luther visit is associated with 9.0 percentage-points higher probability of Reformation adoption. Similarly, towns that sent students to study with Luther were 9.7 percentage points more likely to adopt the Reformation ($p < .05$, see column 5), and each additional student is associated with a .7 percentage-point greater likelihood of adopting the Reformation ($p < .01$, see column 6). Having *any* connection to Luther's network is associated with a 12.4 percentage-point higher probability of Reformation adoption ($p < .05$, see column 7). This provides support for a Luther effect on early adoption of the Reformation. Finally, the first component of the principal components of the three Luther variables enters positively and strongly significantly ($p < .01$) for both the dichotomous and count variables (see columns 8 and 9).

One issue with the Luther network variables is that Luther's ego network was not random. We adjust for most of the key demand side features: Luther was a churchman and a professor, and his network included numerous churchmen and academics. By adjusting for universities and bishoprics—as well as numerous other marks of socioeconomic status—we believe we largely control for omitted variables. However, other proxies are weak at best. While we control for simple spatial diffusion via distance to Wittenberg and Zürich, these do not come close to accounting for the process of establishing a network. To address this issue, in the next section we include data from the trade route network of the HRE.

ROAD NETWORKS AND SPATIAL CONNECTEDNESS

In reaching an interpretation of the relationship between Luther's ties and adoption of the Reformation, an obvious problem arises in that the places Luther wrote to or visited may have simply been more prone to diffusion by virtue of their network position vis-à-vis other towns. How do we know if Luther's influence increased the odds of a town adopting the Reformation net of its structural vulnerability to diffusion? We address this possibility by including measures of a town's trade-route centrality, which captures the spatial connectedness of towns. If the effect of Luther's letters or visits remains significant in a model predicting reform when measures of a town's network centrality are included, then we have greater confidence in our interpretation of the Luther effect.

To estimate these relationships, we reconstructed the network between cities in the HRE as revealed by their location on the contemporaneous regional and long-distance (*Handels-und Fernhandelsstrassen*) trade routes. Based on the historical atlases of Berthold (1976) and Magocsi (2018), we coded cities as having a direct tie to another city if they occupied adjoining positions on overland trade routes or if they could be reached directly through river traffic or sea routes. Our starting point for the network analysis is the 300 cities used in the regressions in Table 2, but we use a slightly different sample. First, we include Erfurt, Wittenberg, and Mecklenburg, which we dropped in the regression analysis. We also add 62 cities that either had missing population data in 1500 in Bairoch and colleagues (1988)—and hence were dropped in the regressions—or were "relevant" cities outside the Holy Roman Empire. We included the latter cities in the network analysis to avoid creating an impression of an isolated node relative to the overall network when that node was in fact connected. For instance, a town only connected to Copenhagen would actually have been well connected to other north German towns, but this would not have been apparent had we dropped Copenhagen from the network data. Finally, the network analysis drops 37 of the original 300 regression cities that are not in the network maps. The network analysis thus includes 328 cities.

Table 3. Descriptive Statistics of the Whole Trade Route Network

Variable	Value
Density	.010
Transitivity	.231
Number of cliques	1067
Mean distance	7.236
Diameter	18.0

Note: Density indicates the number of ties. Transitivity captures the tendency for cities connected to a common city to also be connected. Cliques capture groups of cities where every city is connected to another, such as closed triads. Mean distance indicates the average path length to connect to another city. Diameter is the number of paths in between the two farthest cities in the network. $N = 328$.

Table 3 shows the resulting network's characteristics. The trade route network was relatively sparse, with Wittenberg occupying a parochial position. This structure is in accord with much of what we know about late-medieval Central European geography. Contemporary limits on transportation determined its sparseness. Long-distance trade, particularly overland, was expensive and road quality was poor. Medium-sized cities usually served as regional trading centers. Shipping was cheaper and the largest cities and trading centers tended to be located along navigable rivers or sea harbors (Nicholas 2003; Rozman 1978; Russell 1972; Scott and Scribner 1996).

One way to use the trade network data is to compute measures of the position of a city in the overall network, using measures such as degree, closeness, betweenness, and eigenvector centrality scores and add them as additional regressors. To the extent that these measures capture the cost of travel to a city, a hitherto omitted variable that may have affected both a city's position within Luther's network and its propensity to adopt the Reformation, our previous estimates of Luther's influence might be upwardly biased. The regression results presented in Table 4 show this may have been the case.[21] Many of the Luther network coefficients get smaller—although they tend to retain their statistical significance—when controlling for various measures of network centrality. Yet, to the limited extent that these results are different from those presented in Table 2, most differences come from the drop in observations. (Recall that 37 cities in Bairoch and colleagues [1988] that are used in the regressions of Table 2 are not in the trade network data.) In Table S7 in the online supplement, we rerun the specifications presented in Table 2 with the 263 observations used in Table 4, and we find results similar to those in Table 4. In other words, addition of the city centrality variables does little to alter the primary results connecting Luther's network and the spread of the Reformation.

THE EFFECT OF LUTHER'S NETWORK VIA NETWORK SIMULATION

The regressions provide evidence relating to our simple influence hypotheses as captured by Luther's personal network: even when controlling for various city characteristics, including accessibility by trade, contacts with Luther remained significant. Nevertheless, such regressions do not directly address the counterargument that the Reformation spread through spatial diffusion via trade routes (Hypothesis 3), nor does it allow the possibility that Luther's effect had interdependent effects with spatial diffusion (Hypothesis 4). To explore these possibilities, we turn to computer simulations.

Simulations have been widely used in the social sciences to explain behavioral diffusion (Centola 2018; Heckathorn 1993; Macy 1990), as they bear two advantages. First, simulations can help explore causal effects, as the researcher can "turn on" or "turn off" factors and examine subsequent outcomes without worrying about confounders. Second, simulations allow for *interdependent processes* between factors. For instance, suppose Luther converted city A, and, via trade routes, city A converted two additional cities B and C, then B and C further converted cities D, E,

Table 4. Determinants of Reformation Adoption by 1530, Including Network Variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Dependent Variable: Protestant by 1530								
Luther letter dummy	.117								
	(.071)								
Number of Luther letters		.026**							
		(.010)							
Luther visit by 1522 dummy			.152*						
			(.074)						
Number of Luther visits				.074*					
				(.032)					
Luther students dummy					.136**				
					(.052)				
Number of Luther students						.009*			
						(.005)			
Any connection to Luther dummy							.143**		
							(.053)		
First principal component of Luther variables (dichotomous)								.056**	
								(.017)	
First principal component of Luther variables (count)									.050**
									(.018)
Degree	.003	–.000	.007	.007	.008	.011	.005	.003	.002
	(.019)	(.020)	(.018)	(.018)	(.018)	(.018)	(.018)	(.019)	(.019)
Closeness (x1000)	–.435	–.260	–.352	–.330	–.572	–.487	–.535	–.436	–.317
	(.719)	(.722)	(.704)	(.686)	(.792)	(.739)	(.798)	(.735)	(.724)
Betweenness (/1000)	.017	.018	.010	.012	.014	.007	.015	.013	.011
	(.014)	(.015)	(.013)	(.014)	(.014)	(.016)	(.014)	(.013)	(.015)
Eigenvector	–.019	.016	.007	–.005	–.048	–.092	–.035	.031	.006
	(.191)	(.194)	(.189)	(.186)	(.195)	(.185)	(.193)	(.193)	(.193)
City-level controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	263	263	263	263	263	263	263	263	263
No. of clusters	129	129	129	129	129	129	129	129	129
Pseudo *R*-squared	.387	.395	.398	.401	.403	.386	.402	.420	.410

Note: Robust standard errors clustered by territory are in parentheses. Average marginal effects of probit coefficients reports for all regressions. City-level controls include dummies for the printing press, whether a city printed a work by Luther (in columns 1, 3, 5, 7, and 8), the number of printed works by Luther (in columns 2, 4, 6, and 9), independent city, university, bishop, lay magnate, on water, Hanseatic league, log of population in 1500, market potential in 1500, log distance to Wittenberg, log distance to Zürich, latitude, longitude, and the interaction of the city's coordinates. All regressions include a constant term (not reported). Distance to Wittenberg and Zürich are in km. Wittenberg and Erfurt, Luther's two places of residence, are not included.
$^{*}p < .05$; $^{**}p < .01$ (two-tailed tests).

and F. This snowball effect originating from Luther's influence is a path-dependent process that cannot be revealed through conventional regression analysis.

We use an epidemiological approach to study the spread of the Reformation (Centola 2018; Centola and Macy 2007; Hedström 1994). We imagine the Reformation as a "disease" emanating from Wittenberg, and we consider two possible routes through which infection might spread. The first is a *trade route network* in the HRE, which captures routes of mobility via space. Second, we construct *Luther's influence network*, defined as a personal link between Wittenberg and the city if Luther wrote a letter to, personally visited, or had a student in that city. Each city either adopts or does not adopt the Reformation according to a *decision rule* based on the cities to which it is connected via the network(s). Thus, which cities are predicted to adopt depends on (1) the decision rule and (2) the configuration of the network(s).

Manzo and colleagues (2018) inspired the framework of our simulations. We propose several scenarios/models of diffusion, aiming to recover the mechanisms of historical diffusion. To evaluate the plausibility of the simulations, we identify simulation targets based on summary statistics from historical data. Scenarios that produce results close to the target statistics make the mechanisms plausible, whereas scenarios that produce results far from the target statistics are unlikely to accurately reflect the historical reality.[22]

Simulation Target Statistics

We use the historical data to help us validate the simulations. The network includes all of the 328 observations from the network data described in the previous section.[23] The primary target of our simulations is the number of adopted cities. We calculate the average number of cities that adopted the Reformation in equilibrium (i.e., until no cities further changed their adoption status), and compare this to the actual historical number. In our dataset, 68 of the 328 cities adopted the Reformation by 1530, so the target of the simulations would be to recover this number closely.[24] If our simulations predict many more or many fewer adopted cities, then we may not be capturing the correct diffusion mechanisms.

Although the number of adopted cities is the primary target, more than one scenario can lead to the predicted outcome of 68 adopted cities. We thus further validate the simulations by assessing (1) the conditional probability of adoption if the city was under Luther's influence, and (2) the spatial distribution of the converted cities. For the first assessment, we compare the proportion of cities adopted under Luther's influence with the probability in the simulations. Our data show that 36 percent of the cities subject to Luther's personal influence adopted the Reformation. We consider this an *upper bound* of the true probability because the relationship does not control for any confounders, such as city-level characteristics. With the exception of religious influence in a city, all of these confounders should *positively* bias the basic correlation relative to the true causal probability. Indeed, results in Tables 2 and 4 indicate that Luther's effect on a city adopting the Reformation was less than 36 percentage points. Thus, in the simulations, we treat any probability of Luther's influence on Reformation adoption greater than .36 as improbable.

For the second assessment, we compare the mechanisms of the simulation scenarios to the network graph of the adopted cities. For instance, if the Reformation spread purely via spatial diffusion from Wittenberg, the network graph should reflect this mechanism by showing a large cluster of adopted cities centered at Wittenberg.

There are two major differences between our simulations and previous research on diffusion (e.g., Centola 2018; Centola and Macy 2007; Heckathorn 1993; Macy 1990). First, previous research often conducted simulations in hypothetical networks and experimented with structural network factors such as density or transitivity.[25] In our simulations, we draw on empirical networks constructed

from historical sources, and thus the structural characteristics of the networks are fixed. Second, most research has studied diffusion in a single network with a single decision rule.[26] By contrast, we conceptualize diffusion as the interaction of multiplex networks and multiple processes. Hence, the trade network and the Luther ego network may both contribute to the spread of the Reformation, but the decision rule for the trade network and the Luther network may differ.

The General Algorithm

For each scenario, we run the simulation procedure as follows:

1. We set up an initial cluster consisting of Wittenberg and its immediate neighbors via trade routes, and the neighbors of neighbors. This initial cluster of seven cities establishes the initial basis of diffusion.
2. Depending on the scenario, the *decision rule* for subsequent adoption will change. For each iteration, each city will either adopt or remain unadopted depending on the decision rule. Once a city adopts the Reformation, it cannot revert to unadopted status. We make this assumption because we find no evidence of reversion prior to the onset of religious warfare that began after 1530 in our data.
3. We run the simulation until we achieve an equilibrium (i.e., no cities change their adoption status) and document the number of cities adopted.
4. Because each simulation is a stochastic process, the outcome would be slightly different for each simulation. We replicate the simulations 500 times and calculate the average number of cities that adopted the Reformation.
5. We compare the average number of cities that adopted to the actual number of cities adopted by 1530, which is 68 cities. The simulations should attempt to recover this number. If there is more than one scenario that predicts around 68 cities, we consider the two additional methods of validation (i.e., spatial distribution and the conditional adoption probability under Luther's influence).

We emphasize that the goal of the simulations is to examine *the general mechanisms* by which Luther's influence contributed to the spread of the Reformation. We do not pretend that the simulation is an empirical confirmation of our model. For this reason, our primary interest is to compare theoretical scenarios rather than calibrate parameter values for the decision rules. Although the parameters of the decision rules affect the simulation outcomes, they are not of primary interest. For example, whether the threshold for spatial diffusion is two or three does not help us understand mechanisms of diffusion, as the parameter value is tied to the case of the Reformation. However, whether the Reformation spread via spatial diffusion, Luther's influence, or a combination of spatial diffusion and Luther's influence yields general theoretical implications for how radical innovations spread. Thus, although we considered other simulation methods and conducted robustness checks with different parameter values, we elected to use a parsimonious model to prevent obstruction of the central theoretical insight.

Theoretical Scenarios

In our theoretical formulation, we proposed three potential mechanisms through which the Reformation could have spread: diffusion via Luther's personal network (simple influence hypothesis), spatial diffusion via trade networks (alternative hypothesis), and a combination of interdependent processes of Luther's network and spatial diffusion (multiple diffusion hypothesis). These mechanisms motivate us to consider three simulation scenarios. We document the setup of each scenario and the specific algorithms below (the pseudo-code is included in the online supplement).

Scenario 1: Spatial Diffusion via Trade Routes

In this scenario, the Reformation spreads from the Wittenberg cluster via spatial diffusion. The network is the trade route network. Several micro-mechanisms could foster this stepwise diffusion process (Centola and Macy 2007; Chwe 2000). Adoption by a neighboring city could trigger emotional contagion, create strategic complementarity, enhance credibility, increase legitimacy, or trigger coordination. These micro-mechanisms encompass a wide range of possible varieties of social influence or rational coordination.[27] However, our goal is to examine *city-level* mechanisms (Luther, spatial, or multiple). Hence, for purposes of this simulation, we are agnostic as to which micro-mechanism is the most likely. The specific algorithm for Scenario 1 is as follows:

1. Set up the network as the trade network.
2. Set up an initial cluster of Wittenberg and six neighboring cities via trade as adopters of the Reformation.
3. For each iteration, for each focal city, if the number of neighbors that have adopted the Reformation crosses the threshold of two, the focal city adopts the Reformation.
4. Run the simulation until no cities change adoption status.
5. Record the total number of adopted cities.
6. Rerun steps 1 to 5 for 500 replications, and calculate the average number of adopted cities.
7. Use additional targets for further comparisons if necessary.

We set the threshold of spatial diffusion to be a minimal complex contagion threshold of two (see, e.g., Centola 2018), but we considered higher threshold values. Yet, as seen in the Results section, higher values yield similar theoretical implications.[28] For the sake of theoretical clarity, we focus on a simple version.[29]

Scenario 2: Diffusion via "The Infectious Luther" but No Spatial Diffusion

In this scenario, we investigate the influence of Luther but without the spatial diffusion process: this is the Luther network. To address the infectiousness of Luther, we assign a parameter P_{infect} to construct the decision rule. This single parameter is a simplification of the true process, as we treat cities that Luther visited one time and cities Luther visited multiple times equally. However, the theoretical goal is to examine if a small probability of infectiousness based on a single contact (Luther) could have affected diffusion of the Reformation. For the cities influenced by Luther, with probability P_{infect} the city adopts the Reformation. The specific algorithm for Scenario 2 is as follows:

For the parameter space of P_{infect} = [.1, .2, . . ., .7]:[30]

1. Setup the network as Luther's personal network.
2. Set up an initial cluster of Wittenberg and six neighboring cities via trade as adopters of the Reformation.
3. For each focal city, if the focal city is connected to Luther, the focal city adopts the Reformation with a probability of P_{infect}.
4. Record the total number of adopted cities.
5. Rerun steps 1 to 4 for 500 replications, and calculate the average number of adopted cities.
6. Use additional targets for further comparisons if necessary.

Scenario 3: Interdependent Processes of the Infectious Luther and Spatial Diffusion

This scenario considers the interaction between infection via Luther's network and spatial diffusion via the trade route network.

The networks are the trade network and the Luther network. There are two sets of decision rules, each for different networks. For the trade network, we again apply the decision rule of a minimal threshold of two. For the infectious Luther, we again assign the parameter P_{infect} and the associated decision rule. We first run diffusion via Luther's network, then spatial diffusion via the trade network.[31] The specific algorithm for Scenario 3 is as follows:

For the parameter space of P_{infect} = [.1, .2, . . ., .7]:

1. Setup the first network as Luther's personal network.
2. Set up an initial cluster of Wittenberg and six neighboring cities via trade as adopters of the Reformation.
3. For each focal city, if the focal city is connected to Luther, the focal city adopts the Reformation with a probability of P_{infect}.
4. Add the second network as the trade network.
5. For each iteration, for each focal city, if the number of neighbors that have adopted the Reformation crosses the threshold of two, the focal city adopts the Reformation.
6. Record the total number of adopted cities.
7. Rerun steps 1 to 6 for 500 replications, and calculate the average number of adopted cities.
8. Use additional targets for further comparisons if necessary.

We evaluate the above theoretical scenarios using the statistical software R and report the results below.

RESULTS

Results for Scenario 1 (Spatial Diffusion via Trade Routes)

For Scenario 1, the average number of adopted cities is seven, which is exactly the number of cities we initially set up to adopt. This number is far below the target number of 68 in the data. We also ran two robustness checks. First, we ran a variant of the scenario where, if only one neighboring city connected to the focal city adopts the Reformation, the focal city has a small chance (10 percent) to adopt. In this version, the average number of adopted cities is 13.46, which is still far below the historical number. Second, we increased the threshold, and results did not change.

In other words, a theory of pure spatial diffusion is un-supported. This is because Wittenberg and its surrounding cities were isolated in the periphery of the network with few connections to other cities. Unlike the present, when modern communication tools allow many connections between cities, during the sixteenth century, cities had far fewer contacts, which mainly resulted from trade routes that ran through sparse road and waterborne paths. Thus, there was not enough social reinforcement to form "wide bridges" (Centola 2018) to further the spread of the Reformation, and we do not find support for Hypothesis 3.

It appears there was no spatial pathway through trade networks for the Reformation to diffuse far beyond Wittenberg and the surrounding area. Under these conditions, the Reformation would have remained a regional sect and not become a far-flung movement. In the following scenarios we show that this structural trap can be overcome by adding Luther's infectiousness.

Results for Scenario 2 (Diffusion via "The Infectious Luther," but No Spatial Diffusion)

In this scenario, depending on the parameter P_{infect}, the average number of adopted cities differs, as seen in Table 5. Overall, even with a small probability of infectiousness, the number of adopted cities far exceeds the results in Scenario 1. However, for the target number of 68 cities to adopt, the infectious probability would have to be around 56 percent. This is implausible, because it implies

Table 5. Average Number of Adopted Cities by Luther's Infectiousness (Scenario 2)

P_{infect}	Number of Adopted Cities
.1	18.04
.2	28.87
.3	39.81
.32	42.25
.4	50.82
.5	62.08
.56	68.51
.6	73.27
.7	84.31

Table 6. Average Number of Adopted Cities by Luther's Infectiousness (Scenario 3)

P_{infect}	Number of Adopted Cities
.1	26.15
.2	46.76
.3	62.08
.32	68.55
.4	80.89
.5	93.70

minimal resistance to adoption and is unsupported by the observed data. According to the empirical data, only 36 percent of the cities personally influenced by Luther adopted. As noted before, we view this as an upper bound on Luther's actual effectiveness. Even in the most optimistic of situations in which Luther's effectiveness was indeed 36 percent, Scenario 2 predicts that fewer than 50 cities would adopt the Reformation.

Results for Scenario 3 (Interdependent Processes of the Infectious Luther and Spatial Diffusion)

We next examine whether the combination of Luther's influence and spatial diffusion better explains the spread of the Reformation. Again, as seen in Table 6, the average number of adopted cities varies with P_{infect}. Allowing for the subsequent spatial diffusion of the Reformation following Luther's personal contact, his infectiousness does not need to be as high for the movement to spread. An infectious probability of around 32 percent predicts a number close to the target number of 68, which is below our estimated upper bound of 36 percent. Empirically, as well as theoretically, this scenario premised on multiple diffusion processes is the most plausible.

We further examine the plausibility of this scenario by comparing the mechanism with the network graph of the historical data. In Figure 7, we plot the trade network, Luther's influence, and if the city adopted the Reformation. If the mechanism of Scenario 3 is correct, we should expect cities that Luther influenced to be more likely to adopt. We should also expect that due to spatial diffusion, these cities should be connected to one another as dyads, triads, or even small clusters. This is what we observe: a high proportion of square nodes (cities Luther influenced) are also red nodes (cities that adopted the Reformation) (see the online version of the article for color figures). Furthermore, the red nodes tend to connect as clusters, such as the Bremen cluster in the top of the plot, the Speyer cluster in the left of the plot, and the Erfurt cluster in the middle-bottom of the plot. These clusters have many red circle nodes, indicating that although they were not under Luther's direct influence, they were indirectly influenced by him because they were connected via trade routes to cities Luther directly influenced.

We consider a series of additional descriptive statistics in Table 7 further to examine the validity of Scenario 3. Whereas the overall proportion of cities in the simulation dataset that adopted was 19 percent (Statistic 1), the proportion that adopted under Luther's influence was 36 percent (Statistic 2), supporting the Luther influence part of Scenario 3. Examining the combined effect of Luther's influence further with spatial diffusion, we find that of all the cities that were trade neighbors of cities that were both under Luther's influence and adopted the Reformation, 47 percent also adopted (Statistic 3). This suggests that

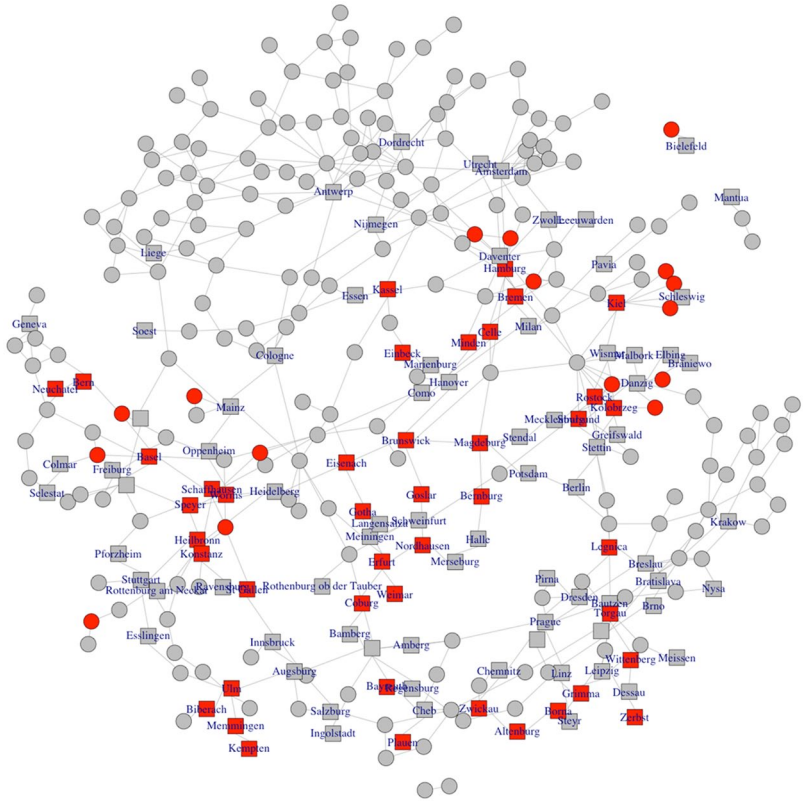

Figure 7. Plot of Trade Network and Reformation Adoption
Note: Gray nodes are cities that did not adopt the Reformation; red nodes are cities that adopted the Reformation (see the online version of the article for color figures). The lines between nodes indicate trade routes. Square nodes are cities that Luther influenced (also labeled by text); circle nodes are cities Luther did not influence.

Table 7. Advanced Descriptive Statistics on Networks and Adoption

Statistic Number	Description	Value
1	Proportion adoption by all cities	.19
2	Proportion adoption of cities in Luther's network	.36
3	Proportion adoption of cities that were neighbors of adopting cities within Luther's network	.47
4	Proportion adoption of non-Luther network cities that were neighbors of adopting cities within Luther's network	.39
5	Proportion of cities adopting among those with zero neighbors that adopted	.06
6	Proportion of cities adopting among those with one neighbor that adopted	.33
7	Proportion of cities adopting among those with two or more neighbors that adopted	.64
8	Average distance to Wittenberg for cities that adopted	208.53

being a trade neighbor of an adopted city under Luther's influence was associated with a higher rate of adoption. Even if we only consider the subset of cities that were themselves not under Luther's influence (Statistic 4), the adoption proportion was still 39 percent, much higher than the overall adoption rate. We further show that of all cities that had zero neighbors adopting the Reformation, only 6 percent adopted (Statistic 5). Of the cities that had one neighbor adopting the Reformation, 33 percent adopted (Statistic 6), and 64 percent of cities with multiple adopting neighbors adopted (Statistic 7). This supports our hypothesis that adoption likely occurred when cities received support from trade route neighbors that adopted. Finally, to show that this trade diffusion effect was unlikely to originate from Wittenberg, we show that the average distance to Wittenberg for adopting cities was 208 km (130 miles) (Statistic 8). In summary, the empirical evidence as well as the network simulations support Scenario 3, and thus our theory of multiplex networks and multiple diffusion processes.

The results of the simulations support Hypothesis 4. The diffusion of the early Reformation appears to have been a combined process of two mechanisms. First, Luther infected a certain proportion of the cities in which he had influence, often far from Wittenberg, which then adopted the Reformation. Because of their spatial relation to uninfected cities, these adopted cities created local social reinforcement that persuaded further cities to adopt, even if they were not directly under Luther's influence. Moreover, Luther's personal influence affected cities that were connected to one another, imitating the cluster activation that is necessary for further diffusion to spread via space (Centola 2018). The result was a wildfire effect that raised the number of adopted cities from around 42 (see Table 5) to around 68 (see Table 6). It appears that the interaction of multiplex networks (trade routes and Luther) via multiple diffusion processes (threshold-based adoption and Luther's infectiousness) jointly facilitated the spread of the early Reformation. The examples of Ribe, Oldenburg, and Winterthur discussed earlier provide illustrations of how these multiple processes might have operated together to induce adoption.

Multiplex networks and multiple processes may also help explain "negative" cases, that is, why some cities remained un-infected despite ties to Luther. To cite one prominent example, several cities in the Low Countries had personal ties to Luther but did not adopt the early Reformation (see Figure 7). These included important trading centers such as Antwerp, Amsterdam, Dordrecht, Nijmegen, and Utrecht. Historical evidence suggests that, despite ties to Luther, their structural position may have exposed them to strong conservative counter-pressures that stifled the early Reformation. For one thing, they were strongly tied to the orthodox Catholic network based at the nearby universities of Louvain and Cologne (Kim and Pfaff 2012). Anti-Protestant "controversialists" were active early on in this region and urged cities to hold fast to the Roman Church (Bagchi 1991). These cities also had many trading ties with anti-Protestant countries (Wurpts et al. 2018). Finally, imperial influence was strong because the region was governed by Habsburg regents and their allies who empowered local magistrates to censor Lutheran texts and arrest (and in some instances, execute) Protestant preachers and agitators as heretics. Luther's influence was effectively neutralized (Tracy 1990:147–60).

DISCUSSION

Limitations of the Study

Empirically, data limitations and the lack of true counterfactuals make the interpretation of historical diffusion outcomes difficult (Palloni 2001). It obliges researchers to combine recorded data on the actions of influential people, reconstructed social networks, and dynamic simulation models to gain insight into observed patterns (see, e.g., Roux and Manzo 2018). If our regressions were perfectly specified without any omitted variables, we could interpret the coefficients on the Luther network

causally. Unfortunately, this is unlikely to be the case. Luther's network—even prior to 1523—was not random. We addressed this issue by posing counterfactuals via simulations that helped isolate Luther's influence on the spread of the Reformation. The results of the simulations back a causal interpretation, but they are not empirical proof of it. Orthodox pressures and countervailing networks may have operated simultaneously alongside Luther's personal networks and Protestant spatial diffusion in some cities. Although we included a host of measures to capture such factors in the regression model, and the framework of complex diffusion presumes resistance to adoption, we have only simulated pro-adoption processes here. Future research should explore the more complex dynamics resulting from competing networks.

Implications for Theory and Research on Network Diffusion

Our study contributes to resolving empirical and theoretical puzzles. Empirically, our analysis sheds new light on one of the great, enduring questions in the social sciences: why the Reformation spread so rapidly and where it did so, given that previous attempts at reform were successfully suppressed or failed to diffuse widely. Whereas scholars have thoroughly analyzed the political processes of the "magisterial" Reformation, the early phase of the Reformation when it had the character of a social movement is relatively neglected (see the review of the empirical literature in Becker et al. 2016).

We developed a model of social diffusion that helps shed light on the puzzle of the Reformation's success. By combining the personal infectiousness of an ideological entrepreneur who can traverse spatial distances by influencing cities linked to his personal network with spatial diffusion through complex contagions, we can better explain the spread of the early Reformation than can theories based solely on printing or that rely on the structural properties of networks alone. In our analyses, Luther's influence conspicuously increased the odds that a city would become Protestant net of a host of other factors that may have predisposed a city to adopt or resist. Nevertheless, we posited that Luther's influence would probably be insufficient to account for the widespread adoption of Protestantism from a network diffusion perspective. It would have also benefited from spatial diffusion unleashed by neighboring cities' adoption of the Reformation. To explore this theoretical scenario, we conducted simulations that allowed us to illustrate the dynamic and interdependent processes that could have combined Luther's influence with spatial diffusion. We show that our model can account for why the early Protestant movement broke out of regional isolation and overcame resistance.

Sociologists have long sought to capture the effect of leadership on social outcomes, usually by referring to "charisma." Weber (1978:241) explained that charisma is the sense of divine authority that makes certain leaders appear extraordinary and worthy of strong emotional attachment. We think it better to consider Weber's conception in relational terms, as a property of the linkages between leaders and followers, rather than as a personal endowment (Duling 2000; Madsen and Snow 1991). Our approach combines relational and structural thinking. We should be wary of "great man" arguments, but our findings suggest caution in going too far in the opposite direction—that is, by claiming that individuals do not matter for historical processes or that structure but not the contents of social relations matter (Erikson 2013). The effect of leadership is discernable in the relational work conducted by people who aspire to influence others. Leaders increase the infectiousness of their ideas by offering novel understandings of problems and prescribing solutions. They cultivate close relationships with those in their intimate circles while reaching beyond them to persuade local elites. Their outreach bridges social and spatial distance but also builds strong personal attachments. Their successful entrepreneurship reflects both structural advantages and relational strategies (Chwe 2000).

As such, our results speak to how opinion leaders contribute to the spread of behavior in two ways (Valente and Davis 1999; Valente and Pumpuang 2007; Watts and Dodds 2007). Traditionally, opinion leaders have been examined in terms of their structural properties in the network, such as whether they have more ties to others (Valente and Davis 1999; Watts and Dodds 2007). However, as exemplified by Luther, it may not only be the number of ties that characterize the importance of opinion leaders, but their *influential power* when they connect to others. From the data, we cannot know whether Luther had an unusual number of ties relative to others in similar occupations, but we could establish whether Luther was "infectious" via his personal relationships. Luther's success appears to be attributable, in part, to relational cultivation of social ties and personal persuasiveness.

Luther's network was not sufficient to spread the movement extensively. The Reformation spread extensively when ties created by personal relationships with Luther combined with *additional ties* operating between the cities through trade relationships. In other words, opinion leaders are only the first condition, and full-blown diffusion may require the second condition of wide bridges and a critical mass consisting of communities that were first persuaded to adopt (Centola 2018; Macy 1990), making coalitions among the early adopters all the more significant for diffusion (Centola 2013). Influence models should thus examine not only the structural position of the opinion leader, but also the characteristics and cohesion of the followers, who, as evidenced by the students trained at Wittenberg, may prove decisive factors in widening the reach of innovations. Our study points to the importance of multiplex ties and multiple diffusion processes and suggests the relational basis of the ties between leaders and followers may be different from the relational basis of the ties amongst followers. Consequently, different degrees of infectiousness and adoption thresholds may occur across groups in the same diffusion event.

Our article also provides evidence for why the widely used "distance to Wittenberg" instrument for the Reformation, pioneered by Becker and Woessmann (2009), works. The idea behind the instrument is that the Reformation spread out from Wittenberg, an otherwise unimportant city. Our findings suggest why this was the case: early adoption of the Reformation was especially likely in what one may think of as "Lutherland"—the areas of Germany proximate to Wittenberg. This is because Luther's social network grew out of personal ties forged through his correspondence, personal journeys, and student apostles. Although Luther also made extensive ties, they were more likely to link him to towns near Wittenberg. Nevertheless, Luther's infectiousness seems to account for why cities that were distant from Wittenberg or poorly connected by roads became early adopters of the Reformation.

Our findings also draw attention to the limitations of current theories of diffusion. Theories of threshold-based adoption argue that significant behavioral changes require multiple sources of contact to spread (Centola 2018; Centola and Macy 2007; Granovetter 1978; Valente 1996). However, save for the handful of cities neighboring Wittenberg, for most cities Luther was their single relational contact to the early Reformation. If changes could occur only through multiple sources of contact, these cities would not have adopted.

Luther was "infectious" in converting places where he had personal contacts, which seems to indicate the activation of "simple contagion." This leads us to reconsider the *relational basis of structural diffusion*. Scholars have conventionally approached network problems from either a formalist approach that stresses network structures, or a relational approach that emphasizes the content and meanings of social interactions (Erikson 2013). The fact that Luther's ties bridged social gaps and created shortcuts in otherwise spatially distant cities is a structural mechanism. However, this structural property would not have been effective without Luther's infectiousness. His infectiousness is not a feature of network structure but rather a relational property of his ties to others.

Generally, studies of social contagion have relied on a single type of tie and a single type

of diffusion mechanism. However, such a framework is insufficient in our case. Neither Luther's personal network nor the trade network was enough to explain the spread of the early Reformation. Luther's infectiousness made the diffusion process via his personal network different from the diffusion process via trade routes, and it is the interdependent combination of both that appears to have made the early Reformation successful. Our study points to how empirical research on diffusion might benefit from a synthetic model that jointly considers multiplex ties, multiple diffusion processes, and highly contagious agents.

Authors' Note

All authors contributed equally to the manuscript.

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Notes

1. In social network analysis, social ties are relations that serve as conduits through which information, opinions, resources, and influence can flow. Social network concepts and methods are revolutionizing the study of religious movements (see, e.g., Everton 2018).
2. By hyper-influential, we mean a person is highly infectious in her ability to influence and persuade others and not necessarily that the person has a different social-structural position or network than others (see Watts and Dodds 2007).
3. Political opportunities at the global level also played a role. The Ottoman advance into Central Europe diverted Catholic military and political resources away from suppressing Luther's movement and toward the "existential threat" posed by the Turks (Iyigun 2008).
4. On the history of Konstanz and Überlingen, see Enderle (1990) and Vierordt (1847). After its defeat in the Schmalkaldic War, Konstanz lost its independence and the Habsburgs forcibly reinstituted Catholicism.
5. At that assembly, an alliance of Protestant cities, princes, and estates presented the "Augsburg Confession," an official explanation of their theological position and a de facto declaration of independence from the Roman Catholic Church (see Becker et al. 2016).
6. Luther's correspondence network does not reveal ties to family members during our period of study. Luther left home at about 12 years old to pursue his education and rarely returned, particularly after entering an Augustinian monastery in 1505 (Brecht 1985). Although excommunicated in 1520, he continued to live in a monastery and wore a monk's habit through 1522. Luther did not marry until 1525.
7. In 1515 and 1516, Luther inspected Augustinian houses where he met with monks and took the opportunity to speak and teach, as well as preach in cathedrals (Köhler 1880:44–49). En route to the Heidelberg disputation in 1518, Luther met the Bishop of Würzburg, and at his destination, he met with dozens of local monks and theologians, as well as Count Wolfgang of the Palatinate (Köhler 1880:57–59). On his 1521 journey to the Imperial Diet, Luther stopped in several cities where he met with mayors and preached. In Worms, Luther spoke before the diet and met with many aristocrats and notables, including Landgrave Philip of Hessia and the Duke of Schleswig-Holstein (Köhler 1880:118–44).
8. The *de facto* HRE did not include Switzerland, the Netherlands, or northern Italy, all of which gained some form of independence from the empire by the period in question. We run robustness checks, reported in Table S3 in the online supplement, using the *de facto* HRE as the universe of observations. Results are similar.

9. We also drop Mecklenburg, where it is ambiguous as to whether population numbers from Bairoch and colleagues (1988) refer to the small town of Mecklenburg or to the territory.
10. We have data on students from the time Luther showed up at Wittenberg in 1512. In Table S4 in the online supplement, we show that students who arrived at Wittenberg prior to 1517 did *not* affect the spread of the Reformation. However, the number of students from a town in the entire decade 1512 to 1522 is positively related to early adoption of the Reformation.
11. Luther lacked a secretary, felt besieged by incoming mail, and had no deliberate policy of saving letters (Brecht 1985:77; Roper 2017:xxxi–ii). Luther's outgoing letters seem to have had a high survival rate because they were intentionally saved by their recipients and frequently copied and distributed. Enemies, too, kept Luther's letters, because they were evidence that could be used (and was used) against him in the court of the emperor and the pope (Greengrass 2016:437).
12. We supplement Buchwald's (1929) *Kalendarium* with the more complete documentation provided by Schneider (2011). We double-checked the entries in Buchwald (1929) and Schneider (2011) by coding all locations Luther visited that are referenced in the all-encompassing biography of Luther by Brecht (1985). These sources are consistent with each other. We thank Thomas Kaufmann and Volker Leppin for valuable advice and for pointing us to Buchwald (1929).
13. In an alternative specification, we include the first two principal components. The coefficient on the first component is always similar to the one reported in Table 2, and the second component is always highly insignificant. These results are available in Table S5 in the online supplement. In the first component composed of dummy variables, the letter dummy loads .600, the visits dummy loads .571, and the student dummy loads .560. In the first component composed of count variables, the letter variable loads .626, the visits variable loads .548, and the student variable loads .554.
14. In Table S6 in the online supplement, we report the same specifications estimated using linear probability models. Results are largely similar in terms of magnitude and statistical significance.
15. Rubin coded this variable from historical atlases and the *Catholic Encyclopedia* (2017). A city receives a value of 1 "if it accepted the Augsburg Confession, Catholics were forced to flee, or the [Catholic] encyclopedia explicitly states the Protestantism was accepted" (Rubin 2014:283).
16. In the next section, we analyze the trade network of the HRE and determine various network attributes of each town, including its degree, closeness, betweenness, and eigenvector centrality scores.
17. To account for local (e.g., cultural) unobservables, we could control for Imperial Circle fixed effects. Much of the HRE was split into six Imperial Circles in 1500, and most of the remainder was split into four Imperial Circles in 1512. Because these boundaries did not really reflect shared cultural or historical experience, we do not include them in the primary regressions. We report results with Imperial Circle fixed effects in Table S8 in the online supplement. The results are largely similar in magnitude to those reported in Table 2.
18. All regressions are clustered at the level of the local territory.
19. For the sake of brevity, we only present the coefficients of interest. Full results are available upon request.
20. In Table S5 in the online supplement, we report estimates that break down the letters into those written in Latin and German. We find that the association between Luther's letters and Reformation adoption was primarily driven by letters written in Latin. This is not surprising; theologians and priests would have been influential in religious matters, and previous work suggests they were among the most important sources of Protestant diffusion in the early Reformation (Blickle 1984; Hannemann 1975).
21. Note that the city-level centrality measures are on the whole network level rather than on the dyad level, as we aim to test the alternative hypothesis regarding general exposure to trade. We add dyadic diffusion analysis to the simulations section. Additionally, our dataset lacks the temporal sequence of adoptions by cities, limiting the usefulness of dyadic measures.
22. Manzo and colleagues (2018) use Euclidean distance as the simulation targets, whereas, as shown later, we use number of adopted cities, conditional proportion of adoption under Luther's contact, and spatial patterns. We did not use Euclidean distance because we do not have precise measures on when a city adopted the Reformation, thus precluding the dimension of time required for a Euclidean distance measure.
23. Robustness checks that use the subsample in the regression analyses yield similar results (see the online supplement).
24. The spread of the Reformation is a single realization of multiple mechanisms, so we do not aim to exactly predict 68 cities. However, our predictions from the simulations should not differ from this number too much.
25. However, historical networks have been used by Manzo and colleagues (2018).
26. This refers to each simulation run. The network and decision rule may vary across different simulations.
27. Although we emphasize that network diffusion is an interdependent process, the underlying micromechanism(s) would be difficult to observe given the nature of the historical data available, and it is beyond the scope of this article.

28. Because Wittenberg was so isolated in network and geographic terms, even with different decision rules it would have been difficult for the Reformation to spread beyond the Wittenberg cluster solely through spatial diffusion. Theoretically, it would have been possible for the Reformation to spread beyond the Wittenberg cluster if extreme parameter values are chosen. For instance, if we chose parameters such that being connected to a large city like Leipzig would be associated with an adoption probability of 95 percent, the Reformation would surely have spread beyond "Lutherland." Nevertheless, we think such extreme values are unrealistic in the spread of high-cost, radical innovations. Consequently, the substantive implication that Luther's personal network was critical (see Scenario 3) to the early Reformation remains similar.
29. We could consider other decision rules, including weighting not only by network distance but also by geographic distance, population size, similarity between city characteristics, or network centrality, as well as including a small probabilistic component in the decision rule, or changing the threshold to be not absolute numbers but rather relative proportions within tied alters. We leave these as extensions to be explored in future work. We elected to present the current simple version of spatial diffusion because it clearly presents the central mechanism. Additional parameters do not help elucidate general diffusion mechanisms.
30. We only estimated up to .7, as that threshold already yields unreasonable results.
31. However, as seen later in results for Scenario 1, because pure spatial diffusion never spreads beyond the Wittenberg cluster and we run the algorithm indefinitely until no cities change their adoption status, altering the timing of when we introduce the Luther effect does not change the results.

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