The Dynamics of Social Hierarchy

A thesis submitted for the degree of Ph.D

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Author Declaration

I declare that this thesis, The Dynamics of Social Hierarchy, represents my own work, except otherwise stated. None of the work referred to in this thesis has been accepted in any previous application for a higher degree at this or any other university of institution. All quotations have been distinguished by quotation marks and the sources of information specifically acknowledged.

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Abstract

A growing body of research has outlined that humans gain social rank through two pathways: prestige and dominance. This dual model of social hierarchy advocates that individuals either attain positions of high rank though signals of an ability and willingness to either inflict harm (dominance) or confer benefits (prestige) to group members. While there is growing support for the dual model of social hierarchy, the extant empirical evidence has been cross-sectional and has neglected the impact that time and context has on the efficacy of prestige and dominance as long-term processes. The present research outlines a theoretical framework for the trajectories of prestige, dominance and social rank over time, and further provides longitudinal evidence of their temporal dynamics. In addition, the current research tests the longitudinal associations that prestige and dominance have with social networks, Results of study 1 suggest that, in collaborative task groups, prestige has a positive and bidirectional temporal association with social rank, while the association that dominance has diminished over time. Study 2 indicated that in these task groups those high in prestige were more likely to be asked advice and prestige was transmitted through advice ties but had a limited association with friendship. Those high in dominance were less likely to be nominated as friends, but dominance was transmitted through friendship ties. Results from Study 3 suggest that those high in prestige status were more likely to aid in food sharing and food production, and that the prestige status of an individual's food sharing and food production partners increased their prestige status over a period of twelve years among the Tsimane forager-horticulturalists of Bolivia. Overall, the present research highlights the distinction between prestige and dominance over time and shows that prestige, dominance, social rank and social networks have bidirectional, dynamic relationships over time.

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Author Note

Chapters 3 to 5 of this thesis were written as independent pieces of research, with the aim of being submitted as peer-reviewed manuscripts for publications. As such, there is considerable overlap in theoretical outlines and methodological descriptions throughout. Chapter 3 is currently under review in Evolution and Human Behavior. Chapter 4 is being prepared for submission in Journal of Personality and Social Psychology. Chapter 5 has been submitted to Nature: Human Behavior. As these are North American journals some chapters use US English as the default language. All of these journals use APA formatting.

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Social hierarchy as a dynamic system

The present body of work investigates how prestige and dominance operate in human groups over time. While the extant literature has suggested that there are two distinct routes to rank attainment, dominance—through fear, manipulation and coercion—and prestige—through respect and admiration—the empirical evidence has provided only a cross-sectional snapshot of how the processes operate. The effectiveness of dominance and prestige as long-term as long-term processes remains an open question. The present research aims to address this gap by first assessing the dynamic relationships that dominance, prestige and social rank have in collaborative task groups. The current research further examines the relationships that prestige and dominance have with social networks over time among both collaborative task groups and the Tsimane forager-horticulturalists of Bolivia. This chapter provides an overview of the literature and offers a theoretical framework for the longitudinal distinction between prestige and dominance.

1.1.Social hierarchy

The differentiation of social rank within and between social hierarchies has been an important piece in solving the puzzle of human evolution. Humans are social animals, living in groups and often seeking contact with others (Leary & Baumeister, 2017). Social hierarchy—the differentiation in social rank between individuals—seems universal to these social groups (Brown, 1991), being observed from the most egalitarian of cultures (von Rueden, Gurven, & Kaplan, 2010) to the formalized organizational structures that characterize contemporary businesses (Magee & Galinsky, 2008). Social rank is defined as an individual's or group's relative position within a social hierarchy based on their social influence and agency (Anderson & Kilduff, 2009b; Báles, Strodtbeck, Mills, & Roseborough, 1951; J. Berger,

Rosenholtz, & Morris Zelditch, 1980; Henrich & Gil-White, 2001). Rank asymmetries develop informally and relatively spontaneously in groups (Bass, 1985; Blau & Scott, 2003). The relative social rank of individuals becomes established through the perceptions of proximate others (Anderson, John, Keltner, & Kring, 2001) and group members tend to agree upon judgments of rank positioning (Mast & Hall, 2004). Based on these judgements of social rank, individuals defer to high-ranking group members, conferring them substantial influence over the discourse of the group (Cheng et al., 2013).

The salience of social hierarchy and rank differentiation is on account of the group and individual benefits that it grants (Christian, 1970; Kaiser, Hogan, & Craig, 2008). At a group level, rank differentiation—and the outcomes of rank differentiation (i.e. leadership)—can provide a platform for solving coordination problems, facilitating cooperation and further limiting costly conflict between individuals (Glowacki & von Rueden, 2015; Lorenz, 1966; Szabó & Fath, 2007). Attaining social rank, at an individual level, also affords many benefits, with those in the apex strata of a hierarchy enjoying greater well-being (Anderson, Willer, Kilduff, & Brown, 2012) and considerable influence over social, sexual and material resources (Barkow, 1975; Betzig, 1986; Buss, 2005; Patton, 2005). Social hierarchy may also have deleterious outcomes for low-ranking individuals, such as when material or social benefits are not equally portioned and corruption is institutionalized, or when asymmetries result from structural coercion or lack of available exit options(Brief, Buttram, & Dukerich, 2001; Leavitt, 2005; Sidanius & Pratto, 2001). However, the many functional aspects of rank differentiation that provide stability, cooperation and

order may explain the ubiquity of the phenomena (Alexander, 1979; Anderson & Brown, 2010; Neuberg & Newsom, 1993; Van Vugt, 2006; Von Rueden, 2014).

A longstanding literature provides a trait-based framework for rank attainment. Stemming from personological models of leader emergence (Carlyle, 1993; Cowley, 1928) that claim that high social rank was the property of extraordinary individuals who possessed personal qualities that defined their effectiveness (Galton, 1869). Some of such relatively stable individual differences are the individual's cognitive abilities (Kickul & Neuman, 2000), their physical strength and size (Knapen, Blaker, & Pollet, 2017; Stulp, Buunk, Verhulst, & Pollet, 2013) or their personality (Judge, Bono, Ilies, & Gerhardt, 2002; Lord, De Vader, & Alliger, 1986). A preference for a number of these traits has also been highlighted in small-scale societies. For example, egalitarian groups tend to confer social rank to those harbouring a prosocial personality (Bird & Power, 2015; Hawkes & Bliege Bird, 2002; Von Rueden, Gurven, & Kaplan, 2008). These traits may, at times, stably predict social rank across situations. For example, evidence from task-based groups has indicated that those who organically emerge as leaders in one group will also become leaders when placed in a group that is focussed on an unrelated task and is composed of different members (Zaccaro, Foti, & Kenny, 1991).

1.2. The dual model of social hierarchy

While these relatively stable traits may individually predict social rank, evidence suggests that their efficacy may also be variable. Considering the joint contributions of these rank-enhancing characteristics may provide a more realistic

representation of how individuals attain and maintain social rank (Yukl, 2008; Zaccaro, Kemp, & Bader, 2004). These rank-enhancing characteristics are defined as a collection of qualities that may reliably distinguish those that are high-ranking from their low-ranking conspecifics across environments (James & Mazerolle, 2001; Zaccaro, 2007). Although some may argue that combining such qualities may not capture some of the potentially important disparities in the association that these traits have with social rank in isolation (Cowley, 1928; Judge et al., 2002; McCrae & Costa, 1997), the complex behaviours that may amount to leadership are rarely grounded in a limited number of individual determinants (Stogdill, 1948; Yukl & Van Fleet, 1992). For example, experimental evidence suggests that social rank can be predicted by an individual's generosity (Barclay, 2013; Barclay & Willer, 2007; Hardy & Van Vugt, 2006) as it honestly signals an individual's quality and ability to access resources (G. Roberts, 1998).

However, one needs to fully recognise the process that amounts to the individual's generosity and extract the antecedents of that individual's access to resources. Thus, to gain a more holistic understanding of the process, the constellations of traits that lead to resource acquisition must be assessed in unison, not in isolation. Assessed in isolation generosity does not make a good hunter or a hard worker. Rather, those high in conscientiousness (Anderson et al., 2001; Hogan & Ones, 1997), those harbouring embodied capital (i.e. physically stronger and larger: Kaplan, Lancaster, & Robson, 2003), and those possessing relevant knowledge and skills (Henrich & Gil-White, 2001), are likely the most able to produce and acquire resources. Only jointly can these personal qualities amount to the individual being able to honestly signal their quality through generosity and to focus solely on one trait

in isolation may blur the broader picture. In combination, many of the narrower traits that predict social rank comprise two distinct psychological profiles (Cheng & Tracy, 2014; Cheng, Tracy, & Henrich, 2010; Henrich & Gil-White, 2001), signalling an individual's ability and willingness to either inflict harm upon, or confer benefits to, group members.

1.2.1 Dominance

Traits that successfully signal an ability and willingness to impose costs comprise a dominance profile. Attaining social rank through dominance is reliant on an individual's propensity to induce fear of psychological, material and physical costs that the individual may impose upon their conspecifics (Buss & Duntley, 2006; Chance, 1967). Dominance has a deep phylogenetic legacy and likely persisted due to the prevalence of intergroup conflict throughout human prehistory that created a selection pressure for both physical and behavioural formidability (Manson & Wrangham, 1991; Wrangham & Peterson, 1996).

Physical formidability, resource control and the ability to impose costs

Given the importance of discerning who is most able to inflict harm upon others, it seems that humans have evolved cognitive capacities for extracting formidability-relevant information from morphological, or non-verbal, signals to dominance (Sell et al., 2009). Some of these signals may be the individual's physical strength and size (Blaker & Van Vugt, 2014), which may indicate to others their perceived aggression and ability to succeed in agonistic encounters (Archer, 1988;

Gallup, White, & Gallup, 2007). Other visual characteristics, such as masculine facial characteristics (i.e. height-to-width ratio, more prominent feature brow), are believed to be signals of an individual's dominance (Little & Roberts, 2012). These facial characteristics, with links to testosterone, signal an individual's formidability, fighting ability and propensity for dominance-related behaviors (Carré, Putnam, & McCormick, 2009; Stirrat, Stulp, & Pollet, 2012). Alongside this, auditory cues may signal an individual's dominance. Deeper vocal acoustics can convey an individual's threat potential through its stable relationship with physical strength and size and testosterone (both endogenous and exposure during development:(Bruckert, Liénard, Lacroix, Kreutzer, & Leboucher, 2006; Feinberg, Jones, Little, Burt, & Perrett, 2005). Expressions of vocal pitch are, however, dynamic and it seems that those high in dominance are disposed to modulate their pitch to invoke signals of their formidability, whilst those lower in rank or dominance reactively modulate their pitch to accommodate their high-dominance counterpart (Cheng, Tracy, Ho, & Henrich, 2016). While some evidence indicates that these markers do predict an ability to impose costs on others—and have further been observed to predict an individual's social rank (Keating, Mazur, & Segall, 1981; Klofstad, Anderson, & Peters, 2012)—recent evidence suggests that these relationships are likely to be small (Haselhuhn, Ormiston, & Wong, 2015).

Individuals high in dominance may maintain power through a monopoly over resources, be they material or sexual (Mazur, 1985). Individuals who are physically formidable, and thus have a greater chance of success during agonistic encounters (Archer, 1988), are more able to aggressively control group resources and face fewer costs (Hammerstein & Parker, 1982; Petersen, Sznycer, Sell, Cosmides, & Tooby,

2013). The defensibility of these resources has broad implications for the steepness of social hierarchies. When resources are scarce and certain individuals have disproportionate control, competition and rank asymmetries become heightened (Pierce & White, 2006). Low ranking individuals are likely to acquiesce to the wishes of a physically dominant individual through fear of both physical harm and also of the individual withholding valuable resources (Hawley, 1999; Mazur, 1985).

However, physical formidability alone is a noisy signal and can also signpost an individual's ability to generate benefits for others (Blaker et al., 2013; Lukaszewski, Simmons, Anderson, & Roney, 2016), thus also being an attribute associated with prestige. Physical formidability is a form of embodied capital, whereby the narrower traits that comprise formidability (i.e. muscle mass and height) are biologically costly investments that take a great deal of time and energy to develop (Kaplan, Lancaster, & Robson, 2003). The information conveyed by physical formidability is multidimensional as the development of such traits can improve an individual's hunting and foraging ability (Apicella, 2014; Gurven, Kaplan, & Gutierrez, 2006; Jones & Marlowe, 2002) and aid in community defence (Van Vugt, Hogan, & Kaiser, 2008), alongside cueing an ability to inflict harm. The combination of physical formidability and individual differences in personality, motivations and emotional profile that signal an individual's willingness to inflict harm upon others (Cheng, Tracy, & Henrich, 2010) delivers a distinct profile that disposes certain individuals to propagate fear among group members.

Dispositional dominance and the willingness to impose costs

There are stable individual differences in the psychological profiles that make certain individuals disposed to dominance (Henrich, 2016). Individuals high in dispositional dominance are high in a combination of narrower personality traits, having high levels of aggression and extraversion, and dominance being marginally associated with neuroticism (Cheng et al., 2010). Moreover, those high in dominance are also narcissistic self-aggrandizers and dominance has a negative association with genuine self-esteem and agreeableness (Cheng et al., 2010). This profile is linked with hubristic pride, which is marked by arrogance and conceit, and is further associated with poor mental health, lack of conscientiousness and an inability to forge and maintain stable, positive relationships (Tracy, Cheng, Robins, & Trzesniewski, 2009). However, hubristic pride may have evolved to motivate a willingness to impose costs on others. The related subjective and egocentric ideals of grandiosity and superiority may provoke anti-social behaviors that induce fear among conspecifics, which has reproductive and social benefits that balance the negatively associated outcomes (Ashton-James & Tracy, 2012). Furthermore, the combination of these stable traits and egocentric status motivations increases an individual's willingness to inflict costs on others to obtain goals (Sijtsema, Veenstra, Lindenberg, & Salmivalli, 2009).

The costs and benefits of dominance and cost imposition

There is a plethora of individual benefits for high-ranking individuals whose positions are derived from signalling an ability and willingness to impose costs on others. In several small-scale societies, males high in dominance have greater reproductive success (von Rueden & Jaeggi, 2016) and achieve positions of considerable influence (Konečná & Urlacher, 2017). Experimental evidence has also

indicated that males perceived high in dominance are more attractive as short-term mates (Kruger & Fitzgerald, 2011). Those high in dominance also have a greater likelihood of becoming leaders and to receive deference and achieve positions of high rank in both formal (Magee & Galinsky, 2008) and informal hierarchies (Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013).

While individuals high in dominance may impose costs on their counterparts, evidence also suggests that groups may, on certain occasions, benefit from the dominant inclinations of certain group members. There are fewer individuals vying for influence in dominance hierarchies, which may ease tensions within a group, facilitate effective coordination (Ronay, Greenaway, Anicich, & Galinsky, 2012; von Rueden, Gurven, Kaplan, & Stieglitz, 2014), and punishment of norm violators (O'Gorman, Henrich, & Vugt, 2009). Individuals high in dominance may also provide group benefits during times of intergroup conflict (Wilson, Hauser, & Wrangham, 2001). Such individuals may inflict costs on an out-group, increasing the competitiveness and success of an in-group (Halevy, Bornstein, & Sagiv, 2008). It is important, however, to note that these group benefits are by-products of those high in dominance creating fear to attain their egocentric goals. Recent evidence indicates that dominance-related social rank does not depend on (mis)perceptions of contributions from high dominance individuals (Cheng, Tracy, & Henrich, *in prep*). Thus, the benefits that may result in rank-relations weighted by dominance are a result of the fear of retribution that subordinate individuals harbour.

Constraining dominance and cost imposition

In many human groups there are several mechanisms that restrict an individual's ability to impose costs on group members. Humans are unusual in the ease with which they form cooperative groups and coalitions(Gintis, van Schaik, & Boehm, 2015). Coalitional groups can attain a multitude of fitness-enhancing outcomes in comparison to individuals acting in isolation (Price, Cosmides, & Tooby, 2002). One such outcome is the ability to coordinate action against those who impose costs on others (so-called '*reverse dominance*': Boehm, 2009). Many groups exhibit an aversion towards exploitative dominance-related strategies and groups members are more likely form alliances (Eibl-Eibesfeldt, 2017; Gavrilets, 2012); spread negative gossip (M. Feinberg, Willer, & Schultz, 2014); dislike (Anderson & Willer, 2014); or exit the group when there are available options (Price & Van Vugt, 2014) to counter the influence of an individual high in dominance.

1.2.2 Prestige

In contrast with dominance, human groups tend to exhibit a near-universal preference for individuals harbouring a distinct constellation of traits, which comprise a prestige profile, and signal an individual's ability and willingness to confer benefits to others. This profile is centred on fostering respect and admiration from proximate others (Barkow, 1975). Alongside the combination of traits that signal an individual's ability and willingness to confer benefits, there is also a set of traits and abilities for those potentially low in prestige to detect the signals displayed by their willing and able group members (Henrich, 2016). Human prestige likely intensified alongside the increased interdependence of individuals within societies for subsistence, with humans pooling both labour and resources to make possible the skill-intensive

foraging niche (Winterhalder, 1986). Within this niche, resource-sharing facilitated the evolution of high fertility and a long juvenile period of development as mothers and children are often subsidized by other community members (Gurven & Walker, 2006). Through this increased interdependence there became an enhanced need for cooperation, coordination of collective efforts and leadership (Van Vugt, Johnson, Kaiser, & O'Gorman, 2008). Alongside this, specializations in labour by sex, age and ability allow individuals to amplify their reputational gains from resource sharing (Hooper, Demps, Gurven, Gerkey, & Kaplan, 2015), with individuals being able to offer inalienable commodities of value to others (Lewis, 2002).

Cultural evolution, prestige bias and the ability to confer benefits. The increasing ability for specialization in a domain relevant to survival has facilitated more complex subsistence strategies and technology, of which is costly for individuals to develop and learn alone (Boyd & Richerson, 1988). Individuals often opt to acquire information from proximate conspecifics rather than learning asocially as it provides greater payoffs in a wide range of environments ((Henrich & Boyd, 1998), aiding in learning complex skills (Tomasello, Kruger, & Ratner, 1993) and reducing uncertainty(Kameda & Nakanishi, 2002). The remarkable ability of humans to transmit cultural information across generations has allowed a vast accumulation and modification of adaptive knowledge, allowing us to harness symbolic systems (such as language) and advanced technologies, and settle in a diverse array of environments (Boyd & Richerson, 1988, 1994; Caldwell & Millen, 2008). Cultural learning, in combination with the evolved cognitive mechanisms and capabilities to share and learn cultural information (alongside other capabilities: Alexander, 1990; Barkow, 1989; Barrett, Cosmides, & Tooby, 2007; Csibra & Gergely, 2009), has been central

to human adaptation, conveying adaptive information about the environment, and has shaped human behaviour (Alexander, 1979; Boyd & Richerson, 1988, 2005; Boyd, Richerson, & Henrich, 2011). Innovations within a cultural system often emerge through individuals asocially learning and tracking changes within the environment; however, the majority of individuals rely on learning from others (Henrich & McElreath, 2003).

There are a number of flexible strategies that individuals employ when choosing from whom to learn. These are so-called '*model biases'*, which often enable the avoidance of unreliable or redundant information. Individuals preferentially learn from, for example, those who are successful (Mesoudi, 2008), or use conformist or frequency-dependent biases (Henrich, 2001; Laland, 2004; Rendell et al., 2011). One of such model biases used is prestige-bias cultural transmission. Prestige-bias cultural learning is a process learners discern who to learn from through the attention and deference that a potential learning model receives from proximate others (alongside other sources of information about a model's quality: Henrich & Gil-White, 2001). While many other sources signalling an individual's success and skill may vary across time and context the deferential actions of proximate others can reliably discriminate good from bad models across environments (Henrich & Gil-White, 2001). Experimental evidence has indicated that both children (Chudek, Heller, Birch, & Henrich, 2012; Fusaro & Harris, 2008; Whiten & Flynn, 2010) and adults (Atkisson, O'Brien, & Mesoudi, 2012) utilize prestige-bias cultural learning when assessing from whom they should learn. In return for the informational, social and material goods that a prestigious learning model may provide, learners within a group confer deference, giving them disproportionate social influence and decision-making

power—and thus high social rank—within the community (Cheng et al., 2013; Henrich & Gil-White, 2001; Price & Van Vugt, 2014).

A potential learning model must harbour several traits that aid in the development of skills, knowledge and afford the ability to confer adaptive benefits to others. Individuals may be skilled in a socially-valued area, such as hunting, or have a breadth of knowledge that can be imparted for a model to attract potential learners (Henrich &Gil-White, 2001). For example, evidence suggests that children have an ability to discriminate between competent models who provide reliable information over unreliable (Over & Carpenter, 2012), copying reliable models when learning how to use artefacts (Zmyj et al., 2010) and novel words (Koenig, Clément, & Harris, 2004). Some evidence has suggested that prestige has a curvilinear associate with age, with those in mid-life being deemed most prestigious (Von Rueden et al., 2010) and children being disposed to copying older learning models (Wood, Kendal, & Flynn, 2013). This may be due to age cueing a greater wealth of opportunity to accumulate knowledge, skills, wealth and potentially coalition partners (Benoit-Smullyan, 1944; Henrich & Gil-White, 2001; Reyes-Garcia et al., 2008; Von Rueden, 2014). Physical strength and size may also be an important signal of an individual's ability to confer benefits as it is associated with greater hunting ability (Gurven et al., 2006; Jones & Marlowe, 2002).

Dispositional prestige and the willingness to confer benefits. The ability to confer benefits alone does not found prestige. A potential learning model must also be willing to provide benefits to those around them. Dispositional prestige is associated with high genuine self-esteem, extraversion, agreeableness, conscientiousness and

openness (Cheng, Tracy & Henrich, 2010). Those high in conscientiousness are more likely to focus on learning and practicing skills (B. Roberts, Jackson, Fayard, Edmonds, & Meints, 2009). Genuine self-esteem reflects self-perceived social acceptance (Leary, Tambor, Terdal, & Downs, 1995) and also has a strong relationship with prestige. Prestige is further related to high social acceptance and agreeableness as these trait provide a marker for individuals to monitor their prestige and for others to observe their disposition towards a more humble, prosocial approach to social rank (Ames & Flynn, 2007; Leary, Cottrell, & Phillips, 2001; Paulhus, Robins, Trzesniewski, & Tracy, 2004). In line with this, prestige has a negative relationship with aggression and neuroticism. This reflects the tendency for individuals high in prestige to be emotionally stable and relatively unreactive to interpersonal stress (Cheng, Tracy & Henrich, 2010). Those high in prestige are also disposed to being cooperative and generous, signalling the quality of their cooperative intent (Bliege Bird & Smith, 2005; Price, 2003).

The benefits and costs of prestige. There are a multitude of individual benefits—and relatively limited costs—related to prestige for those high and those low in social rank. Experimental evidence suggests that those high in prestige are more attractive as long-term sexual partners (Kruger & Fitzgerald, 2011) and in a myriad of small-scale societies prestige is linked with higher reproductive success (Alden Smith, 2004). Among the Tsimane, individuals high in prestige are more likely to exhibit superior physical health (Reyes-Garcia et al., 2008) and have lower offspring mortality than other group members (von Rueden et al., 2010). For individuals low in social rank, deference to a high-prestige conspecific facilitates social learning. Proximity to those high in prestige may also provide coalitional and reputational benefits, which may

afford low-ranking individuals beneficial skills and knowledge. Consequently, the association may increase an individual's overall fitness, providing a safety net of support during times of need, and elevate their prestige (see Chapters 4 and 5; Boone & Kessler, 1999; Patton, 2005; Polly Wiessner, 2005). At a group level, prestige may heighten the overall levels of cooperation among non-kin, facilitating more ethical leadership and effective collective action (Henrich & Gil-White, 2001; Hooper, Kaplan, & Boone, 2010; Van Vugt, 2006; Von Rueden, 2014).

1.3 Dynamics systems and the plasticity of social hierarchy

Social rank is not solely dependent on the potentially high-ranking individual's trait expression, but also co-dependent on the trait levels and behavioural reactions of all group members. Humans live in complex, dynamic systems that govern all aspects of their daily lives. These systems are characterised by interlocking components that, over time and at different levels, impact one another bi-directionally (Kenrick, Li, & Butner, 2003; A. Nowak & Vallacher, 1998). These systems can give rise to many group-level qualities and processes. Individuals invest in social learning within the systems, which may give rise to flexibility and relative plasticity of behaviors in adapting to change or to different environmental pressures (Baldwin, 1896; Oyama, Griffiths, Gray, & Russell, 2001; Richerson, 2018). Examples of such processes are assortment due to trait-based similarity, cooperation and normative cultures, which can develop through a number of simple rules that may be guided by the ecological pressures (Boyd & Richerson, 2005; Cosmides & Tooby, 1994; Henrich, Chudek, & Boyd, 2015; M. A. Nowak & Sigmund, 2004; Schoener, 2011). By reducing these processes of selection and social influence down to

understand the impact of a narrower trait on a dependent outcome, some paradigms often neglect the detail that certain behavioural processes are not isolated and provide an incomplete snapshot of temporally-isolated states of a system (Kenrick, Li & Butner, 2003).

1.3.1. The dynamics of prestige, dominance and social rank

Approaching human social hierarchy as a complex, dynamic system can provide important insight as to why prestige and dominance may be successful for rank acquisition and maintenance in some groups, but not in others. Through this, the current perspective extends upon previous integrative approaches to leadership and social hierarchy (Volberda & Lewin, 2003; Yukl, 2006; Zaccaro, 2007), marrying trait-based and state-based paradigms proposed in the extant literature. While trait models of rank attainment and leadership emergence may variably predict an individual's ascendance in social rank, their social rank is situated in context. Individuals who are high-ranking in one situation may not necessarily have the qualitites to be high-ranking in a different situation (Dorfman & Howell, 1988; Fiedler, 2006; Stogdill, 1948). It seems that, whilst the recognition that prestige and dominance are distal profiles that form the core foundations of human social hierarchy (Cheng & Tracy, 2014), there are multiple dynamic signalling systems that may proximally impact an individual's social rank (Bro-Jørgensen, 2010).

Natural selection may have favoured dynamic, proximate behavioural displays that flexibly communicate an individual's motivations associated with rank attainment. The causal dynamics of the prestige-dominance model of social hierarchy

are inherently bidirectional and, whilst this has yet to be empirically tested, facultative flexibility in the expression of both prestige and dominance behaviors may remain throughout development and during adulthood (Cheng, Tracy &Henrich, 2010). The prestige of an individual may exhibit flexibility as their specialized skill or knowledge is centred on information beneficial to specific domain, culture or environment (Flinn, 2005; Lopreato, 1984; Meltzoff, 1995). Moreover, prestige may catalyse a diffusion of prosociality, generosity and cooperation across generations through cultural learning (Chudek & Henrich, 2011; Henrich, Chudek, & Boyd, 2015). Thus, those initially low-ranking, low-prestige learners, over time may become more similar to their prestigious models through social influence and imitation. This, however, has yet to be empirically tested. Individuals may also react to the success or failure of expressions of prestige or dominance, and further modulate their behaviors between the two profiles to accommodate the selective pressures of their current environment. For example, empirical evidence seems to suggest that, when routes to social rank through prestige are blocked, individuals attempt to seize rank through dominance-related behaviors (Fast & Chen, 2009; Fast, Halevy, & Galinsky, 2012; Redhead, 2016). Overall, prestige and dominance may exhibit relative plasticity in expression over time.

Given these oscillations in expression, the history and environmental context in which an individual is placed may explain some of the variance in who becomes high ranking but may not be as important for understanding the difference between high-ranking and low-ranking individuals (Zaccaro et al., 2004). For example, prestige and dominance seem to have a relatively linear relationship with social rank across many situations, suggesting that those disposed to expressing high levels of

either prestige or dominance become high ranking, whereas those displaying low levels are likely the low-ranking individuals (Cheng & Tracy, 2014; Henrich & Gil-White, 2001; Maner, 2017). However, the divergent routes to attaining and maintaining social rank through either prestige or dominance may be contextually-dependent. For example, in many contemporary cooperative groups and small-scale societies there seems to be a premium placed on prestige (Anderson & Kilduff, 2009b; Barkow, 1975; Epitropaki & Martin, 2004; Ridgeway & Diekema, 1989), with many sanctioning expressions of dominance (Boehm, 2009). On the other hand, dominance is salient during both childhood and adolescence (Hawley, 1999; Redhead, 2016; Redhead, Cheng & O'Gorman, 2018), in some small-scale societies (Chagnon, 1989; Garfield & Hagan, in press; Von Rueden et al., 2010), in periods where intergroup tensions rise and conflicts may emerge (Laustsen & Petersen, 2017; Van Vugt & Grabo, 2015) and in unacquainted groups or organizations with formalized power structures (Magee & Galinsky, 2008).

1.3.2 A relational approach to understanding social hierarchy

It seems that, although selection may favour prestige and dominance profiles as predictors of social rank, situational dynamics may weight the contributions of these dispositions. The fluctuations in rank maintenance over context and time may be rooted in the inherently relational nature of social hierarchy, Rank differentiation is complex, dynamic and multi-layered, with individuals operating in networks of interpersonal relationships (Avolio, Walumbwa, & Weber, 2009; Carter, DeChurch, Braun, & Contractor, 2015; DeRue & Ashford, 2010). Emerging evidence suggests that social rank impacts the networks of interpersonal relationships that characterize

groups, whilst these networks of relationships may concurrently influence social rank (Torlò & Lomi, 2017).

At a dyadic level, there cannot be a leader without a follower (Katz & Kahn, 1978) and the efficacy of an individual's prestige or dominance in attaining more favourable rank may be dependent on the levels similarity (or dissimilarity) of their counterpart. At a transitive level some aspects of social rank can be linearly ordered, such that if individual *i* was higher in rank than individual *h*, and *h* higher than *j*, then *i* would be higher in rank that *j* (Gazes et al., 2017). Analogous to this, the attentional structures related to rank allocation suggest that if individual *j* is paying attention to individual *h* and individual *h* to individual *i*, then individual *j* is more likely to attend and defer to individual *i* (Chance, 1967; Cheng et al., 2013; Henrich & Gil-White, 2001). At a population-level, the cultural norms and ecological pressures weight the contribution that the networks of relations have on social rank as responses to the dynamic organizational requirements that they pose (Yukl, 2008; Zaccaro, et al., 2004). Therefore, rank differentiation has relative plasticity, with those embedded in a group exhibiting dynamic strategies that are produced by interactions between particular evolved decision rules and environmental inputs (Gangestad & Simpson, 2000; Van Vugt, 2006).

The relational behaviors that individuals exhibit are guided by their dispositional prestige and dominance, but also impact both perceptions of prestige and dominance. It seems that people-oriented relational behaviours (i.e. emotional support, generosity: Bass, 1990; Yukl, 2006) are associated with the social rank of individuals in situations when the interests of individuals may be relatively divergent

(House, 1971; Van Vugt, Hogan, et al., 2008). For example, during experimental paradigms—where individuals may maximize their personal payoffs through selfish acts—individuals tend to attain high social rank through displays of material generosity (Barclay, 2013; Hardy & Van Vugt, 2006; Milinksi et al., 2002; Willer, 2009). A similar tendency for high-ranking individuals to demonstrate prosocial relational behaviors, such as friendship ties and altruistic exchanges, has been observed in W.E.I.R.D. groups (Western, Educated, Industrialised, Rich and Democratic:Anderson & Kilduff, 2009b; Ball & Newman, 2013) . A similar preference has been shown in small-scale societies. For example, the most skillful hunters tend to share meat among the community (Bliege Bird, Smith & Bird, 2005; Boone, 1998) and prestigious individuals tend to lend high amounts of social support (Power & Ready, 2018; Von Rueden et al., 2008).

In situations when the interests of group members converge, individuals high in prestige may be more likely to invest in task-oriented relational behaviors (Yukl, 2008; Van Vugt, Hogan & Kaiser, 2008). In such situations, individuals high in prestige may use non-forceful persuasive direction and instrumental advice—for example, that related to the task at hand (House, 1981)—to keep others focussed, promoting the successful coordination of the group and further heightening their social rank (i.e. Anderson & Willer, 2014). Individuals lower in prestige and social rank may also actively seek such advice and freely defer to the non-forceful direction of their high-prestige counterpart as it facilitates their social learning in a domain of instrumental social value and may provide net payoffs for the group (Henrich & Gil-White, 2001). Moreover, such social learning from a skilled and knowledgeable individual high in prestige may, over time positively impact the learner's prestige.

Individuals high in dominance seem disposed towards negative relational behaviours to obtain and maintain social rank. The success of these negative ties may be situation-dependent and contingent on a plethora of factors associated with the cultural norms of a group and the composition of a group (Redhead, 2016). For example, in communities where dyadic fighting is not formally or heavily sanctioned, or warfare between other communities is frequent, the aggressive behaviours associated with dominance may be most potent. For example, among the Tsimane of Bolivia, who have no recently reported incidents of inter-community conflict, individuals who have, and also prevail in, dyadic conflicts within the community are often granted high social rank (Von Rueden et al., 2010). In more extreme cases, warriorship success during agonistic conflict is a route to reproductive success and being conferred social rank among the Achuar (Patton, 2005) and the Yanomami (Chagnon, 1989). However, there has also been contradictory evidence for the reproductive success of warriors among the Waorani (Beckerman et al., 2009; Robarchek, 1998). Among adult W.E.I.R.D populations—for example in fraternities, romantic partnerships and formalized organizational hierarchies—individuals potentially disposed to dominance often tease other group members, make forceful task-related demands, are verbally aggressive, spread negative gossip, and ostracise others to attain positions of high ranked (i.e. Case & Maner, 2014; Keltner et al., 1998; Van Kleef et al., 2011). A similar tendency for those high in dominance to generate negative relational ties has been observed in childhood and adolescence with individuals who bully and are verbally or physically antagonistic often being popular and high ranking (Hawley, Little, & Card, 2007; Redhead, Cheng, & O'Gorman,

2018; Sijtsema, Veenstra, Lindenberg, & Salmivalli, 2009; Veenstra, Lindenberg, Munniksma, & Dijkstra, 2010).

While dominance may be associated with negative relational ties, the converse may be observed with its connection to positive relational ties. Dispositional dominance is associated with hubristic pride, which propagates behaviors deleterious to achieving and maintaining social relationships (Tracy & Robins, 2014; Tracy, Cheng, Robins, & Trzesniewski, 2009). Through this, those high in dominance are expected, during adulthood, to be less likely attain and maintain friendships with others and be less socially accepted among groups that sanction dominance-related behaviors (Cheng & Tracy, 2014).

1.3.3. Overview of the current research

The main aim of the current research is to ascertain whether the processes fundamental to social hierarchy in humans are dynamic. That is, do prestige, dominance, social rank and social relationships change over time, and does change in one of these processes impact change in the others? The current research proposes three central hypotheses in relation to this question:

Hypothesis 1: Prestige, dominance and social rank will fluctuate over time, with changes in one of these processes will impact change in the other.

Hypothesis 2: Social hierarchies are embedded in social networks, which are as likely to be a consequence as to be a cause of differences in prestige and dominance.

Hypothesis 3: There are distinct social networks that relate to cooperation in humans, which are multiplex (i.e. ties in one network impact ties in the other) and inherently linked to social hierarchy.

The following chapter (Chapter 2) provides a brief overview of the statistical methods that can best parse dynamic relationships over time and, thus, effectively test the present dynamic theories. Chapter 3 provides a further overview of the dynamic relationships between prestige, dominance and social rank, proposing and testing several predictions related to hypothesis 1 by utilizing a longitudinal design that captures peer-perceptions of prestige, dominance and social rank from the initial formation of naturalistic task groups through to the end of a 16-week semester. Chapter 4 provides both theoretical rational for hypotheses 2 and 3, and empirically tests the proposed relationships by tracking the temporal associations between prestige, dominance, instrumental network ties—operationalised as advice—and expressive network ties—operationalized as friendship—among North American undergraduate students. Moreover, Chapter 5 delivers a further test of hypothesis 2 by assessing the association between instrumental network ties—captured through nominations of food-sharing and help with food-production— and prestige among the Tsimane hunter-horticulturalists of Bolivia over a 12-year period. Finally, Chapter 6 synthesises the current body of research, highlighting the implications that it has for the relevant fields of study and further outlines the future questions posed that the research poses.

2

Dynamic models for dynamic theories

2.1. Modelling Temporal Dynamics: Continuous time structural equation models

Dynamic models cover a broad range of statistical modelling techniques that evaluate how certain processes function within-subjects over time. These processes often follow a smooth trajectory, are sequentially dependent (i.e. autocorrelation/autoregression), have cross-lagged impacts (change in one process causing change in the other), and are guided by small levels of stochastic inputs (i.e. there is a small amount of randomness in changes over time). Until recently, dynamic models have been measured in discrete time, assessing temporal parameters in equal steps, which has constrained the comparability of results and has several data requirements that are not consistently met. Discrete time models centred on the strict assumption that points of measurement are made with the same interval of time between them and, in most cases, this assumption is not satisfied, which can cause bias in parameter estimates. This is due to the strength of autoregressive and lagged effects on processes that are inherently dependent on time (Oud, 2007). Moreover, the assumption of equally spaced time intervals also limits the comparability of studies using discrete time models, with results only being fully comparable between those measuring data in the same timeframe (Voekle, Oud, Davidov & Schmidt, 2012).

Processes unfold over continuous time and continuous time structural equation models can be used to analyse both panel and time series data, with multiple models (such as cross-lagged panel and latent growth curve models) being available (Driver et al., 2017). The focus of this section will be on cross-lagged panel models (Lazarsfeld & Fiske, 1938), which can assess multivariate processes by analysing the lagged effects of predictor variables on a given dependent while controlling for the autoregressive effect of the dependent variable on

itself (Kenny, 2005). The relationship between the predictor and dependent variables is dynamic, with predictor variables, if specified, also being simultaneously and temporally dependent (Oud, 2002). In place of discrete time, the current models consider the discrete observations as part of a latent, continuous time process by estimating the unobserved process using a stochastic differential equation (Driver, Oud, & Voelkle, 2017; Oud, 2002). In doing this, the models account for latent, stochastic processes that have not been measured within the design, parsing informative unpredictable fluctuations in the trajectory of the process (innovation variance)—which may be useful for future predictions—from deviations that are not meaningful (measurement error) and do not offer any predictive value (Driver & Voelkle, 2018). Through this, the models reduce noise and providing a more representative interpretation of the processes under question. The equation below is taken from Driver, Oud and Voelkle (2017) and interpretation of the equation bares similarity to the interpretation that they present.

(Equation 1: Continuous time dynamic model)

$$1) \quad \mathrm{d}\boldsymbol{\eta}_i(t) = (\mathbf{A}\boldsymbol{\eta}_i(t) + \xi_i + \mathbf{B}\boldsymbol{z}_i + \mathbf{M}\boldsymbol{\chi}_i(t))\mathrm{d}t + \mathbf{G}\mathrm{d}\mathbf{W}_i(t)$$

Within the multivariate stochastic differential equation, $\mathrm{d}\boldsymbol{\eta}_i(t) \in \mathbb{R}^v$ is the vector of the variable, v, process of interest for the subject, i, dependent on the time, t, parameter. $\mathbf{A} \in \mathbb{R}^{v \times v}$ is the matrix assessing the temporal relationships of the variable process, comprising the cross-effects of the variable on the off-diagonal and the auto-effects positioned on the diagonal. $\boldsymbol{\eta}_i(t)$ is the longitudinal process level, which is governed by the v-length vector for the random variables, $\boldsymbol{\xi}_i$, which include the continuous time intercepts and subject-level covariance. $\boldsymbol{\xi}_i$ fixes the longitudinal process level and the subject-level

longitudinal differences. $\mathbf{B} \in \mathbb{R}^{v \times p}$ is the matrix showing the effect of the p-length vector of temporally constant, time independent, predictor variables, $\boldsymbol{z} \in \mathbb{R}^{p}$. $\boldsymbol{\chi_i}(t)$ is the effects of time dependent predictors variables, that is predictors that show temporal variation. These time dependent predictors are distinct from the process system in focus and their effects are only assessed during the observation periods. However, this can be modelled differently to include the evolution of the predictors within the model. $\mathrm{d}\mathbf{W_i}(t)$ is the stochastic error term, which is an immeasurably small augmentation of the Weiner process, and $\mathbf{G} \in \mathbb{R}^{v \times v}$ is a lower triangular matrix representing the variance-covariance of the diffusion process over continuous time (a continuous Markov process modelling the temporal trajectory of the process). Overall, continuous time structural equation modelling assesses the expression of traits or behaviours as being products of a process of continuous time, whilst accounting for the dynamic effects of related, modelled processes and time dependent and independent predictors. By doing so, the approach provides a platform for robust and representative tests of relationships between variables. Moreover, extensions of the model allow for multi-level testing with multiple endogenous groups (Driver et al., 2017), and models using Bayesian and hierarchical Bayesian inference with random coefficients (Driver & Voelkle, 2018).

While continuous time modelling does overcome many issues relating to modelling longitudinal data, many approaches do not account for the potentially hierarchical nature of temporal processes. More traditional approaches (i.e. autoregressive cross-lagged panel models) often estimate a single set of fixed-parameter effects, which assume that the processes unfold in exactly the same way for all subjects. However, it is common for the intercept in dynamic models to vary between subjects and not accounting for the subject-specific differences in the average level of a process may bias parameters within the model that are assessing the temporal dynamics (Hamaker, Kuiper, & Grasman, 2015). A hierarchical Bayesian formulation of continuous time structural equation modelling provides

a middle ground between fixed-effects models and subject-specific models by estimating population distributions for model parameters (For a full outline and mathematical description see Driver & Voelkle, 2018). Through this, the model simultaneously estimates the population distribution mean and variance, which serves as prior information and informs the sampling of the subject level parameters as hyperpriors. Hyperpriors are priors that reflect the expectations for the population distribution. Thus, the subject specific parameter estimates are joint-posterior population distributions that are conditional on a combination of the estimated population distribution, which fully accounts for between-subject differences, and the calculated likelihood of parameters being subject specific.

2.2. Modelling network dynamics: Stochastic actor-oriented models

Stochastic actor-oriented models are used to analyse panel data, both social networks and attributes, that have been measured at discrete time points. These data could be naturalistic, survey or pseudo-experimental, if the measures are administered to the same individuals within a network over two or more time points. These models can be applied to networks that are undirected or directed, weighted/ordered, one-mode or bipartite, multiplex (Snijders, Lomi, & Torló, 2013) and multi-level, which either comprise nested actors or sets of endogenous actors (Snijders, 2016; Snijders & Baerveldt, 2003). However, the data must consist of complete networks constructed by participant nomination or explicit interaction. This is due to the models' assumption that—unlike other models within social network analysis (i.e. ERGMs: Lusher, Koskinen, & Robins, 2013) that are tie-oriented—networks are actor-oriented, and actors actively make the decisions that inspire change in network structure. The approach assumes structural individualism—with SAOMs implementing Luce's (1959) choice axioms assumption—that change within the social networks are

contingent on the choices of the individuals (or actors) embedded in the network. The actor-driven changes are further assumed to be products of a Markov process, in which the current state of a network can solely predict its future state, and that these changes are driven by actors evaluating the current network and aiming to maximize its future state (T. A. Snijders, 2009).

This actor-driven change is assumed to be a continuous process, with actors making evaluations at latent periods between observed time points. To meet these assumptions, Snijders (2001) combined mini-step Markov models (Holland & Leinhardt, 1977) with random utility models (Manski, 1977) with actor's choices to create change based on whether such change would maximize their utility. Method of moments estimation implemented by Monte Carlo (MC) methods and stochastic approximation (Robbins & Monro, 1985) is commonly used to estimate such models, given the lesser computational burden of the estimation procedure compared to other methods (Sniders, 2009). However, these models can also be estimated through maximum likelihood using Markov Chain Monte Carlo methods (MCMC) and stochastic approximation (T. A. Snijders, Koskinen, & Schweinberger, 2010), and multi-level models can be estimated with Bayesian estimation using MCMC methods (Koskinen & Snijders, 2007).

Simulations of the process of change are implemented between discrete time points to capture the cumulative sequences of the smallest possible latent changes that amount to the more substantial observed changes. The simulations are conditionally dependent on the state of the first observed network, which is not modelled but used as the starting point for the estimation (Snijders et al., 2010). The opportunity for actors to make these changes are simplified into microsteps, whereby multiple changes are decomposed into the smallest

possible change and only one tie variable can either be created, dissolved or maintained (Snijders, 2009). The rate of opportunity for change for actors is modelled by the rate function (See Equation 1) and is dependent on an actor's position within the network and their attributes (Snijders, 2001). The rate function is formally defined as:

(Equation 1: Rate Function)

$$2) \quad \lambda_i(x) = \sum_k \rho_k r_{ik}(x)$$

Within the rate function, the models speed differences between actors, i, and, alike to Poisson regression, λ_i is a parameter of an exponential distribution of waiting times for a change to occur (i.e. the amount of microsteps between observed periods). k is the degree, and the r_{ik} statistics of actor i's neighbourhood within x are weighed by the model parameters ρ_k. Thus, the rate function produces an estimate of the frequency of change opportunities. For example, if the rate estimate for choice of friends in a classroom network produces an estimate of 3.210 it indicates that actors had 3.210 opportunities to change their outgoing ties between the two observed time points.

Actors' evaluations are modelled using the objective function (see Equation 2), which estimates the probabilities of actors making the choice to create, terminate or continue ties within their network. Theoretically and empirically derived effects (see Table 1) can be modelled into the objective function to assess their impact on actor decisions. Several effects are structural, assessing endogenous network tendencies, and should be included in the models as controls, such as tendency to create ties (outdegree/density), the tendency for reciprocity and at least one network closure effect (i.e. geometrically-weighted transitive

group formation). Actor-attribute, or covariate, effects may also be modelled to test hypotheses relating to the effects of exogenous mechanisms on a network. There is a diverse array of effects, and interaction terms, that can be used to test complex processes that affect network dynamics (see Ripley, R., Snijders, T., Boda, Z., Voros, A., & Preciado, P., 2018)). The objective function for network dynamics is formally defined as:

(Equation 2: Objective Function)

$$3) \quad f_i(\beta, x) = \sum_k \beta_k \, s_{ki}(x) \, .$$

Within this linear function, the value for an actor each, i, is expressed as $f_i(\beta, x)$, with the evaluation being dependent on the state of the network, x, at each microstep and is subject to statistical inference. β_k weights are the statistical parameters and s_{ki} are the included effects that should be theoretically and empirically grounded. Some of such effects that are included in the models are the generally tendency to nominated others (the outdegree or density) and the tendency towards reciprocity. Actor choice between microsteps is modelled as a multinomial model with the outputs interpreted as log-odds ratios. An assumption of this function is that actors maximise their scores and, therefore, a positive estimate produced by the model would indicate that actors are more likely to create or maintain ties based on that attribute, whereas a negative estimate would infer the converse.

Stochastic Actor-Oriented Models for Network and Behaviour Dynamics

Behaviors of actors may have effects on their network's composition, but this relationship is dynamic and the networks in which actors operate may also affect their expression of individual attributes. Actors may create ties with those expressing similar traits (homophily: (McPherson, Smith-Lovin, & Cook, 2001) but the expression of an actor's traits may also be influenced by those

whom they are proximate (Marsden & Friedkin, 1993). SAOMs have been extended to simultaneously estimate changes in both networks and dependent 'behaviours' (Burk, Steglich, & Snijders, 2007; Steglich, Snijders, & Pearson, 2010). These models can parse selection and influence processes, and, highlighting mechanisms for both network and behaviour dynamics. In-keeping with SAOMs terminology and literature, endogenous traits, attributes or behaviours will be referred to as behaviours throughout this section.

It is important to understand that the relationships between behaviours and social networks is fundamentally dynamic and that the outcomes of these relationships should be examined as mutually-dependent products of continuous temporal processes (Steglich, Snijders & Pearson, 2010; Stokman & Doreian, 1997). The relationships between conspecifics emerge through thick webs of complex interactions and are contingent on the relationships, or lack thereof, between others proximate to them (Veenstra & Steglich, 2012). Therefore, it is important for these dynamic relationships to be considered using complete network data for group, with soundly determined boundaries being imposed. This captures the complexities of both direct and indirect ties between individuals. Moreover, the relations being examined are not necessarily stable, with ties between conspecifics changing due to stochastic events, such as arguments or individuals entering or leaving the group, or endogenous network characteristics, for example transitive group formation (Van de Bunt, Van Duijn & Snijders, 1999). Without capturing both the relationships and behaviours at multiple points in time, a cross-sectional design may misattribute the similarity of tied conspecifics as being selection when, indeed, it may be a product of an influence process that arose before measurement (Feld, 1981). It is, thus, important for any complete network data to collected using a longitudinal design and for the statistical model to assess selection and influence processes simultaneously. This dynamic statistical approach can be achieved using stochastic actor-oriented models for the coevolution of networks and behaviours (Snijders et al., 2007; for a detailed review of selection and influence processes see Steglich et al., 2010).

SAOMs for networks and behaviours operate in a similar fashion to models solely assessing network dynamics. Behaviour dynamics are decomposed into microsteps, with the processes unfolding over continuous time and being products of a Markov process. Changes in behaviour are also assumed to be actor-oriented, with actors having agency in the expression of their behaviour as well as their outgoing ties. To fit the current requirements of this model, measures of behaviour must either be, or be transformed into, integer-valued ordinal scales and should have a conservative number of values (with 10 being recommended as relatively high:(T. Snijders, van de Bunt, & Steglich, 2010)). This is due to the assumption of the model that, alike to tie changes, alterations in behaviour can only be at value of one at a single microstep. There are several viable strategies for ensuring that measurements meet these requirements. For example, if working with personality scales, scores may be rounded to the nearest integer, could be transformed into categories using the sample mean and +/- 1 standard deviation, or converted into categorical (Ntile) percentile rank.

(Equation 3: Objective Function for Network and Behaviour)

$$4)\ f_i^z(\beta, x, z) = \sum_k \beta_k^z s_{ki}^z (x, z)\ .$$

Akin to the objective function for network dynamics, $f_i^z(\beta, x, z)$ is the value for an actor and behaviour, with the parameters for network, x, and behaviour, z, evaluation being distinct. The weighting of effects on behaviour change is expressed by the parameters β_k^z. The linear combination of the included effects, $s_{ki}^z(x, z)$, are modelled as dependent upon the actor's behaviour, their position within the network and the behaviour of alters whom they have ties with. As with the objective function for network dynamics, actors are assumed to maximize scores and a positive parameter estimate would indicate an increase in the expression of the behaviour, whilst negative estimate would indicate a decrease associated with the modelled effect.

3

On the dynamics of social hierarchy

1. Introduction

Rank differentiation is ubiquitous in human societies, with social asymmetries being ever present within and between groups (Leavitt, 2005; Wiessner & Schiefenhövel, 1998). Social rank is defined as an individual's or group's relative social influence and agency within a hierarchy (Anderson & Kilduff, 2009a; Báles, Strodtbeck, Mills, & Roseborough, 1951; Berger, Rosenholtz, Zeldtich & Morris, 1980; Henrich & Gil-White, 2001; Magee & Galinsky, 2008). Throughout our evolutionary history social rank and outcomes of rank differentiation, such as leadership, have played important roles, determining group success and providing a platform for facilitating effective coordination, collective action and group decision-making (Glowacki & von Rueden, 2015; O'Gorman, Henrich, & Van Vugt, 2009). An emerging literature across the behavioural sciences indicates that variation exists in the origins and expression of rank differentiation in human groups (i.e.Borgerhoff Mulder, 1987; Hawkes & Bliege Bird, 2002; Power & Ready, 2018). Many forms of rank differentiation appear to be the result of conflict and imposition, but co-existing with this and also prevalent in human societies are hierarchies based on freely conferred deference. How these distinct hierarchies emerge in human groups over time remains an unanswered question. By addressing such a question the current research provides substantial insight into why certain antecedents of social rank prevail in some groups yet appear redundant in others.

The current research provides a theoretical outline of, and tests, the dynamic, temporal relationships between prestige, dominance and social rank. We predicted that both profiles would be effective routes to attaining social rank during initial group formation, but the longitudinal trajectories of the two profiles would diverge with only prestige having a impact on social rank over time. Within collaborative groups, comprised of individuals focussed on performing a specific task and exhibiting no formalized positions of power is

likely to be countered (Boehm, 2009; Boehm & Flack, 2010; Price & Van Vugt, 2014; Van Vugt, 2006), resulting in unstable and thus potentially diminished longitudinal relationship to social rank. Consequently, in groups and societies that have developed strong norms that may either place a premium on prestige, or sanction dominance, the relationship that dominance has with social rank may be muted, whilst in groups and societies that lack these norms, dominance may remain an effective route to social rank (Pandit & van Schaik, 2003).

2. Dominance and Prestige: Two Routes to Social Rank

Humanity draws on a deep phylogenetic history of individuals gaining rank through dominance: the strategic implementation of fear and coercion (Barkow, 1975). Individuals attend to a multitude of visual, auditory and behavioural cues to a peer's dominance, all of which may be signals of their ability to inflict harm and control resources (Maynard Smith & Price, 1973; Mazur, 1985; Sell et al., 2009; Wrangham, 1980). Individuals not only attend to cues of a conspecific's ability to inflict harm, but also to signals of an individual's propensity for behaviours that propagate fear, which comprise a *dominance* psychological profile (i.e. aggression, disagreeableness, narcissism: Cheng, Tracy & Henrich 2010; Henrich, 2016).

Evidence suggests that dominance in humans does indeed provide some distinct fitness pay-offs. In certain contexts, males and females expressing dominance-related traits can be high in social rank and have control over social, sexual, informational and material resources (Buss & Duntley, 2006; Chagnon, 2012; Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013; Griskevicius et al., 2009). Complementary to this, meta-analytical evidence across non-industrial societies indicates that dominance-conferring traits are linked to

reproductive success (von Rueden & Jaeggi, 2016). For example, males perceived high in dominance among Tsimane hunter-horticulturalists of Bolivia (von Rueden, Gurven, & Kaplan, 2010) and males with lower voice pitch among the Hadza (Apicella, Feinberg, & Marlowe, 2007) have a greater number of offspring within their community.

Whilst dominance does seem to predict social rank in some societies, contradictory evidence has emerged that suggests a zero or negative relationship between dominance and social rank in task-based groups (i.e. Anderson, Srivastava, Beer, Spataro, & Chatman, 2006; Ridgeway & Diekema, 1989). In such groups, dominant individuals may not possess exceptional instrumental social value and are neither willing nor able to facilitate the accomplishment of a group's shared goals. Individuals operating in collaborative groups are more likely to defer to conspecifics through processes of respect and esteem, rather than threat and coercion (Anderson & Kilduff, 2009; Chase, 1974; Chase & Lindquist, 2016; Price & Van Vugt, 2014). Contradictory evidence is also found in small-scale societies, whereby dominance seems to relate to social rank in some groups (i.e. Chagnon, 1989; von Rueden et al., 2010), but not in others (i.e.Boehm, 2009; Cashdan, 1980; Kaplan, Hooper, & Gurven, 2009). These inconsistent findings may in-part be due to the different ways that dominance has been operationalized, with measures of physical strength and size, fighting ability (especially in times of conflict) and authority potentially being confounded by perceptions of prestige, providing instrumental value and propagating respect—rather than fear—within a group.

This potential premium placed on respect, skill and esteem in collaborative groups likely emerged alongside humanity's increased interdependence for subsistence (Winterhalder, 1986), the increased reliance on social learning (Henrich & Gil-White, 2001)

and the enhanced need for coordination of collective efforts and leadership (Hooper, Kaplan, & Boone, 2010; Van Vugt, Hogan, & Kaiser, 2008). Prestige bias refers to the process by which individuals preferentially learn from and defer to those who signal valued skills, knowledge and prosocial attributes, also focussing on the attention and respect that potential learning models receive from proximate others to detect the best model (Bliege Bird & Smith, 2005; Henrich & Broesch, 2011). Alongside this, groups are often attentive to cues of an individual's generous intent, signalling a propensity to effectively and ethically steer the group's direction (Glowacki & von Rueden, 2015; Willer, 2009). Therefore, to facilitate coordination and gain proximity to these prosocial, talented individuals and access their skills, individuals confer deference and yield decision-making (Cheng et al., 2013; von Rueden et al., 2014).

It is likely that humans have developed a *prestige* psychology, which encompasses a wide range of emotions and personality traits that are associated with both being and finding an optimal learning model, with individuals signalling and attending to both an ability and willingness to confer benefits (Cheng et al. 2010; Henrich, 2016). These prosocial reputations relate to the amount of socio-economic support and deference an individual receives (Hardy & Van Vugt, 2006; Macfarlan, Quinlan, & Remiker, 2013) and are crucial for prestige to be a stable strategy, as behaving arrogantly or with entitlement may squander away a prestigious individual's status (Ames & Flynn, 2007). This is due to the market-like relationship that underpins prestige, as prestigious individuals do not take, but are afforded social rank and are freely granted distinct fitness-enhancing benefits (i.e. higher reproductive success, positions of leadership: Alden Smith, 2004; Henrich & Gil-White, 2001; von Rueden & Jaeggi, 2016).

3. The Longitudinal Dynamics of Social Hierarchy

Although the extant literature indicates that dominance and prestige are both fruitful for attaining social rank in either unacquainted or pre-existing groups, extant theoretical and empirical research has not outlined the impact that time has on these processes. In the following section, we propose a theoretical framework that integrates time into the dual model of social hierarchy, hypothesising that time may further give rise to a longitudinal distinction between the two processes and their relationship with social rank. We further highlight that whilst prestige and dominance are universal strategies for acquiring social rank, the relative context-specificity of rank allocation norms produces context-specificity in the efficacy of both dominance and prestige for the accrual of social rank.

Social hierarchy and rank relations are inherently dynamic and, in part, context specific. While social hierarchy is thought to be universal (Van Vugt & Tybur, 2015), there are striking differences in the extant cross-sectional evidence examining the antecedents and dimensions of rank differentiation (reviewed in Ridgeway, 2017). It seems that, while we all have a motivation to obtain social rank and feel valued (Anderson, Hildreth, & Howland, 2015), the means by which these positions are obtained may be culturally and contextually determined (Benoit-Smullyan, 1944; Henrich & Gil-White, 2001; Leary, Jongman-Sereno, & Diebels, 2014). Individuals operate in multiple hierarchies in their day-to-day lives. They may be the head of their household, but subordinate in their network of friends or coasting as the middle man in their workplace, with each hierarchy operating on a distinct set of rules for rank allocation (Sewell, 1992). These rules may be governed by the social dynamics of the group, with rank allocation norms being contingent on the reactionary nature of deference within the group. More specifically, the deference behaviors of group members are in response to the actions and traits observed in those around them and, through this reactive

relational dependence, those composing a group often confer social rank to the same individuals (Báles, Strodtbeck, Mills, & Roseborough, 1951; Blau, 1964; Zaccaro, 2007). The norms surrounding rank allocation may further be guided by the task that a group faces, operating in a manner that may maximize group success (Ellis, 1994; C. Ridgeway & Diekema, 1989) or reduce the costs inflicted upon the group by others (Cheng & Tracy, 2014; Mazur, 2005).

However, differences between contexts need time to become salient. In the nascent stages of group formation, or in transient groups of unacquainted individuals, rank asymmetries may be unstable and the norms surrounding the traits that promote social rank are, in most cases, unclear. Therefore, in such groups, rank allocation patterns may differ from those observed in long-term groups. Given the reactionary nature of deference in groups, time is important as it facilitates observations of who other members of the group are attending and deferring to. Evidence confirms that reputation correlates more strongly with history of acts and behaviors for the most prominent individuals in a community (Anderson & Shirako, 2008). Over time, the relationship between contextually-important traits and social rank within a group is not only expected to strengthen, but also be dynamic, with anterior social rank increasing future social rank and potentially feeding back into and increasing perceptions of the processes that increased social rank previously. These dynamic aspects of rank differentiation would suggest that the processes relating to rank acquisition may have divergent impacts on social rank in the different stages of group formation.

Given that individuals high in dominance gain social rank through fear, it is easier for dominance to operate effectively in the nascent stages of group formation, or in transient groups of unacquainted individuals. Evidence suggests that humans possess evolved

cognitive capacities for extracting formidability-relevant information from both morphological and behavioural signals to dominance (Holbrook, Fessler & Navarette, 2016; Sell et al., 2009; Toscano, Schubert, & Sell, 2014). Those high in dominance are also likely to cue social formidability and are more inclined to speak and attempt to forcefully direct group-related tasks. For example, dominant individuals are prone to deepen their voice during initial interaction, speak with force and subtly tease or ostracise others to produce fear (Bendersky & Hays, 2011; Brass & Burkhardt, 1993; Case & Maner, 2014; Cheng, Tracy, Ho, & Henrich, 2016; Keltner, Young, Heerey, Oemig, & Monarch, 1998; Manson, Gervais, Fessler & Kline, 2014). Through these behaviours, the individuals who become more conversationally domineering and interrupt during task-related conversations are perceived higher in dominance and, in turn, higher in social rank in groups of unacquainted individuals (Cheng, Tracy, Foulsham, Kingstone, & Henrich, 2013; Farley, 2008). This evidence suggests that, unlike prestige, the efficacy of dominance in promoting social rank is less reliant on a history of interactions and that cues to dominance may be salient even with limited information.

It is possible that temporally-extended group interactions will mitigate the effectiveness of dominance. Human groups accurately monitor status dynamics and the behaviour of individuals, which may supress the effects of dominance on rank acquisition over time (Anderson et al. 2001; Boehm & Flack, 2010; Wiessner & Schiefenhövel, 1998). For example, as group members become acquainted with one another and exchange information and experiences, the perceived value of members develops (Baumeister, Zhang, & Vohs, 2004; Feinberg, Willer, & Schultz, 2014). Individuals who initially attained social rank due to dominance behaviours may not be perceived as high in social capital or

instrumental social value (i.e. both their ability and willingness to help accomplish an individual's or group's goals: Leary et al., 2014; Lin, 1999). Specifically, cross-sectional evidence suggests that in task-groups of individuals cooperating to accomplish a shared goal, perceptions of an individual's allocentric motives, generosity and task-related competence are most salient in promoting social rank (Anderson & Kilduff, 2009a; Flynn, Reagans, Amanatullah, & Ames, 2006; Griskevicius et al., 2009), which are traits antithetical to those associated with dominance (Cheng, Tracy, & Henrich, 2010).

We propose that the context of time and place is fundamental to the nature of human dominance, with dominance relations being relatively malleable based on the composition of group. Unlike non-human primates, physical strength and size are not necessarily the most essential determinants of victory during agonistic contests between humans. The presence of allies and coalitions shrinks the perceived size and muscularity of a foe (Holbrook, Fessler & Navarrete, 2016; Fessler & Holbrook, 2013) and the widespread development of lethal weaponry potentially neutralizes human physiological dominance (Gintis, van Schaik, & Boehm, 2015). The diminished potency of physical dominance, and increased reliance on manipulation (Clutton-Brock, 2009) and coercion through psychological fear (Henrich & Gil-White, 2001) has altered the manifestation of dominance relationships. This, paired with the aforementioned temporal dynamics associated with rank allocation and maintenance, has constrained the efficacy of dominance as a long-term strategy for attaining social rank in many settings.

For dominance to remain an effective rank acquisition strategy over time, there must be a number of social and socio-structural antecedents. Within groups where aggression, bullying and violence are prevalent and normative, individuals high in dominance-related

traits may take power and increase their rank (Decker & Van Winkle, 1996; Henry et al., 2000; Redhead 2016). In developmental hierarchies, for instance, dominance is associated with popularity and social rank (Redhead, Cheng, & O'Gorman, 2018) and seems most potent for rank acquisition during periods of transition (i.e. between primary and middle or junior high school), when groups and hierarchies are forming (Faris & Felmlee, 2011; Pellegrini & Long, 2003). Moreover, in periods when usually peaceful groups are warring, individuals perceived high in dominance may be preferentially selected as leaders (Little, Burriss, Jones, & Roberts, 2007). A similar partiality for leaders harbouring dominance-related traits has also been observed in formalized hierarchies, whereby the official position of an individual may afford them power and the increased ability to inflict costs on others via reward and punishment (Magee & Galinsky, 2008). In sum, the efficacy of dominance is expected to be less stable and more variable across environments.

Prestige, on the other hand, seems to be universally promoted by groups and communities, and should remain a near-universal stable and effective route for attaining social rank over time. Prestige is marked by the deference of others within the group and should become more potent in promoting rank when greater information is gathered, or needed, about a potential learning model. Whilst there seems to be an innate ability to track and preferentially learn from accurate models (Birch, Vauthier, & Bloom, 2008), during the initial phase of a group's formation all individuals are relatively naïve learners and may not be able to precisely understand a causal connection between a potential learning model's practices and their success (Henrich, 2016). Their judgements about a potential learning model's prestige may rely on less accurate cues to their adaptive knowledge suitable for the given situation, such as attribute-similarity (Losin, Iacoboni, Martin, & Dapretto, 2012) and cross-domain prestige biases (e.g. being carried over from an unrelated field: Henrich & Gil-

White, 2001). This, paired with the amount that potentially dominant others speak and interrupt, are attended to, and are afforded social rank in the initial period of a group's formation may cause these cues to be weaker in the nascent stages of group formation.

This is not to say that prestige is an ineffective process among unacquainted groups, nor that prestige is constrained solely to social learning, but that prestige may become increasingly effective as group members become more acquainted and there are more opportunities to directly perceive success as well as indirect cues to prestige. Additionally, prestige is founded on the desire of others within the group to please prestigious learning models, which is cued by the proximity that peers strive for and maintain, and the deference that these individuals provide to a learning model (Henrich & Gil-White, 2001). Consequently, the accumulation of deference that a model receives and the growing number of proximate others talking positively about them, wanting to be close to and mimicking them may also feed back into the individual's future prestige (Chudek, Heller, Birch & Henrich, 2012). Thus, through a learners' tendency to track prestige cues given off by other learners (i.e., to whom do others attend, defer, and emulate), social rank and prior prestige breed greater future prestige.

4. The Current Research

Given the theoretical grounds for suspecting that dominance may lead to social rank in the early stages of group formation but yield to prestige over time, we designed a study using newly-formed task-based student groups to directly assess the outlined temporal dynamics of the dual model of social hierarchy. We predict that prestige and dominance will

have distinct temporal effects on social rank in collaborative task groups, but over time these relationships will be bidirectional and social rank may also impact on an individual's perceived prestige, but not dominance. The current study utilizes peer ratings of prestige, dominance, and social rank within task-based groups for which membership was randomly determined. The timescale of the present research captured the measures from the stage of group formation through to the completion of the task that the group faced. The current context provides a fruitful platform for evaluating the effects of prestige and dominance, as a sizable collection of individuals collaborated on projects that had a substantial impact on their academic grade—an outcome that is given substantial weight in this model group. Thus, individuals had a vested interest in ensuring that the group functioned effectively, which parallels the dynamics of a wide range of project-based groups that represent how many far-reaching, crucial decisions are made in WEIRD societies (i.e. work groups and teams in organisations, leaders and policy-makers in government: Anderson & Kilduff, 2009a; Ronay, Greenaway, Anicich, & Galinsky, 2012).

4.1 Hypotheses

In light of previous evidence and the theory outlined above we hypothesised that:

H1: Prestige and dominance both predict social rank at the initial time of measurement.

H2: Whilst individuals perceived as high in dominance will have high social rank initially, this relationship will diminish over time.

H3: Individuals perceived as high in prestige will have relatively high social rank initially and this relationship will strengthen over time.

H4: Individual's social rank will feedback and increase their subsequent prestige.

H5: Prestige and dominance will operate independently as distinct processes, such that they will be neither correlated nor impact one another, throughout the study.

5. Method

5.1. Participants. Students (N = 263, 60% female, $\bar{x}$age = 20.67, $SD = 1.38$) at a North American University participated in exchange for course-credit. Participants comprised two classrooms enrolled in the same course taught by the same instructor over two years (classroom 1: n = 123 individuals, classroom 2: n = 140 individuals), and were nested in 66 randomly assigned mixed-sex task groups (classroom 1: n = 30 groups, classroom 2: n = 36 groups) that each had between 3-5 members ($\bar{x} = 4.02$, $SD = 0.33$). Participants worked in the task groups to complete a course project throughout the 16-week semester worth 30% of their final grade.

5.2. Procedure. Every week, participants attended a large lecture for two hours and spent a further four hours working in-person in their randomly-assigned task groups in laboratory sections. At the start of the semester, participants completed a self-report questionnaire in week 1, before meeting the rest of their group. In the remainder of the semester, they completed a further four self- and peer-report questionnaires (in weeks 2, 6, 10 and 16) online. The extra two weeks between the fourth and fifth questionnaires (weeks 10 and 16) were due to the week-long holiday and mid-term exams during this period.

Participants were assigned a unique ID and allotted up to 7 days to complete each questionnaire.

5.3. Self-Report Measures.

Gender. Participants reported the gender that they identify as at the beginning of the study (week 1). Participants were given the choice of 4 categories: 'male', 'female', 'neither male nor female' and 'prefer to not say'.

5.4. Peer-Report Measures.

Prestige and Dominance. Throughout the peer-report questionnaires (weeks 2, 6, 10, 16), participants rated all other members of their task groups on prestige and dominance, using an abridged version (in order to reduce participant fatigue) of the Prestige and Dominance Scaled Questionnaires (Cheng et al., 2010). All ratings were made on a scale ranging from 1 (*Strongly Disagree*) to 7 (*Strongly Agree*). Ratings comprised four items assessing perceived prestige (e.g. "*Their unique talents and abilities are recognized by others in the group*") and four items measuring perceived dominance (e.g. "*They enjoy having control over other members of the group*"). Ratings were then averaged across raters at each time wave to obtain prestige and dominance scores for each participant. Table 1 shows descriptive statistics for all variables. Both prestige and dominance had excellent reliability, with $\alpha > .80$, and were not correlated at every time point (see Table 2 for internal consistency and raw correlations at each time point).

Social Rank. Prior work has used and established the validity of this set of items in predicting actual decision-making capacity within groups (Cheng et al., 2013). Here, participants rated

all other members of their group on three items assessing perceived social influence and three items assessing their perceived agency. The items capturing social influence comprised: "*This person leads the task group*", "*I paid attention to this person*" and "*This person had high status*". The items capturing agency were adapted from the Revised Interpersonal Adjective Scale (Wiggins, Trapnell, & Phillips, 1988) and consisted of: "*This person was assertive*", "*This person was self-confident*" and "*This person is timid*". Responses across all 6 items were averaged at each time wave to yield a composite score for their perceived social rank that had adequate internal consistency at every time-point (see Table 2).

5.5. Analytical Strategy

We assessed the dynamic relationships between prestige, dominance and social rank from the point that the collaborative task groups formed and cast initial peer ratings (week 2 of the study, referred to as T_1 from this point) to the end of the semester (week 16, referred to as T_4) using a hierarchical Bayesian continuous-time structural equation model (from this point referred to as ctsem: for an introduction see Driver & Voelkle, 2018), using the ctsem package (version 2.4.0. Driver, Oud, & Voelkle, 2017) in R (version 3.3.3: R core development team). ctsem utilizes stochastic differential equations that assess processes operating continuously over time and accounts for a number of important short-comings of typical discrete time models (see Driver, Voelkle & Oud, 2017; Driver & Voelkle, 2018). A central strength of ctsem is that hypotheses relating to how change in one process may predict later change in a different process (i.e. cross-lagged effects) are assessed while accounting for stable factors, such as the average level of the process, and also correlated changes at that time point (via the diffusion matrix, see Driver et al., 2017). Through a hierarchical Bayesian framework, ctsem allows for the estimation of continuous time processes of a sample while

accounting for potential subject-level deviations by using population model estimates to inform subject-level model priors, which is a fruitful compromise between more traditional fixed-effects and subject-specific models (Driver & Voelkle, 2018). See supplementary materials for detailed information about the modelling approach.

The ctsem that was applied to our data represents a first order, three-process model of prestige, dominance and social rank dynamics. We specified the default model priors outlined in Driver and Voelkle (2018). Whilst we did not predict effects of gender, gender composition of groups, size of group and cohort, we ran models that controlled for the potential main effects of these variables on the average level of model processes by including them as time-independent predictors. In fact, none of these variables had an impact on any processes, nor did they improve model fit. Moreover, to assess and account for any interdependencies in ratings of prestige, dominance and social rank at the task-group level, a model was estimated where prestige, dominance and social rank were group-mean centred. This also had no impact on our results. Outputs from any of these models are available upon request. Figure 1 illustrates the final estimated model and Equation 1 represents the matrix specification of our subject-level model.

The focus of the model was the drift matrix of temporal dynamics, represented in Figure 1 as regression paths between dominance, social rank and prestige, and the diffusion matrix, which is represented as the correlations between prestige, dominance and social rank at a given time point. The drift matrix illustrates the lagged interrelatedness of the processes on one another (e.g. the effects of dominance at time 1 on social rank at time 2), and the within-subject temporal stability (i.e. the auto effects of prestige on prestige over time). The diffusion matrix represents uncertainty, or noise, in the dynamic model – at any time there

may be changes occurring in the latent processes that the deterministic dynamics given by the drift matrix do not predict, and these random changes can be correlated across processes. In interpreting the model outputs, we assessed the parameter's posterior mean in relation to its posterior standard deviation (SD) and posterior credibility intervals (CI). The CI indicate, with 95% credibility, the probability that the parameter falls between the lower (2.5%) and upper (97.5%) limits. For some parameters it is important to consider if they genuinely differ from zero – for these, if zero does not fall within the upper or lower limits the CI of the parameter, then we conclude that the non-zero parameter estimate is not due merely to sample fluctuations, but is relevant for interpretation.

6. Results

6.1. Do dominance and prestige predict social rank initially in the newly formed groups (H1)?

To examine the impact of perceived prestige and dominance on social rank at the initial time of measurement, we examined the correlations between all three variables at the initial point of the groups meeting (see Table 2 and Figure 2). Non-informative priors were specified, which expressed ignorance to the value and direction of the relationships between prestige, dominance and social rank[1].

There were no significant differences in perceptions of prestige, dominance and social rank based on gender. Nor were there any substantial gender differences in the relationship between prestige, dominance and social rank when assessing males and females separately. Thus, the correlations reported are collapsed across genders. Correlations were consistent

with Hypothesis 1 and suggest that at time 1 prestige had a strong, positive relationship with social rank with the 95% credibility intervals being much greater than zero (ρ = 0.38, *CI* = [0.26, 0.48]). A positive relationship was also found between dominance and social rank (ρ = 0.20, *CI* = [0.08, 0.31]).

6.2 Do prestige and dominance predict social rank over time (H2 and H3)?

The results presented in Table 3 are the posterior mean, standard deviation and CI estimates of the means of the population distributions of the model represented by Figure 1. All parameter estimates reported have far greater than 100 effective samples and the $\widehat{R}$ for all parameters fell between 1.00 – 1.03. As shown in Table 3, there were no notable main effects of gender on the average levels of the three processes, with the credibility intervals encompassing 0.

The population means for the T_0 mean parameters in Table 3 represent the relationship between the subject's initial states with their later states throughout the latent process. A negative T_0 mean implies that the initial state of the process was lower than future states, whereas a positive value would suggest that the initial state was higher. Results indicate no strong tendency for prestige ($\bar{x} = -0.82, SD = 0.54, CI = [-1.73, 0.65]$), dominance ($\bar{x} = 0.19, SD = 1.20, CI = [-1.54, 3.72]$) or social rank ($\bar{x} = -0.66, SD = 0.57, CI = [-1.07, 0.85]$) to increase or decrease substantially over time, as for all parameters zero falls within the CIs. The manifest mean parameters represent the average level of the processes, while the manifest variance parameters reflect random measurement error in the indicators of prestige, dominance and social rank.

The drift parameters of prestige on prestige, dominance on dominance, and social rank on social rank denote the autoregression effects of the processes. The closer these estimates are to zero, the more temporal stability there is in the process – that is, changes in prestige, dominance and social rank persist longer in time. As shown in Table 3 and Figure 3a, changes in dominance persist, as the estimates are closest to zero ($\bar{x} = -0.23, SD = 0.16, CI = [-0.59, -0.02]$). Changes in social rank are the next most persistent ($\bar{x} = -0.66, SD = 0.19, CI = [-1.07, -0.32]$), while changes in prestige appear to dissipate fastest ($\bar{x} = -1.07, SD = 0.22, CI = [-1.52, -0.66]$).

To assess the effects of prestige and dominance on social rank over time we first evaluate the drift matrix parameters that represent the cross effects in Table 3 and are shown in Figures 3b. When a positive value is estimated it reflects that when one process rises, so too does the other, whereas a negative value would suggest a negative effect. Results support Hypothesis 3, indicating that prestige had a positive effect on social rank over time ($\bar{x} = 0.33, SD = 0.15, CI = [0.05,0.66]$). Consistent with Hypothesis 2, evidence for the effect of dominance on social rank over time is less clear, with results indicating that there was no substantial effect, with CI's including zero ($\bar{x} = 0.12, SD = 0.12, CI = [-0.09,0.38]$).

To further understand the temporal relationships that prestige and dominance have with social rank, we turn to the diffusion matrix correlation parameters shown in Table 3. Unlike the results above, which present the causal relationships between processes, these parameters represent the within-subject correlation in the random changes of the latent processes and highlight the extent to which the processes may share common causes. The results align with those of the drift parameters, providing strong evidence that the random changes in prestige and social rank over time may share some common causes ($\bar{x} =$

$0.71, SD = 0.12, CI = [0.46,0.90]$). Random disturbances affecting dominance and social rank processes do not seem related ($\bar{x} = -0.03, SD = 0.12, CI = [-0.25,0.20]$).

Furthermore, the between-subject correlations shown in Table 3 indicate that average levels of prestige had a high correlation with average levels of social rank ($\bar{x} = 0.78, SD = 0.12, CI = [0.42,0.90]$). Whereas, the near-zero between-subject correlation for dominance and social rank indicate average levels of the processes tended to have a limited correlation ($\bar{x} = -0.02, SD = 0.20, CI = [-0.48,0.31]$). With respect to our hypotheses about the temporal effects that dominance has on long-term social rank (H2), results are inconclusive – if dominance does have an effect, it is not substantial in this sample.

6.3. Does social rank increase prestige, but not dominance, over time (H4)?

To assess the concurrent effects of social rank on prestige and dominance over time, we examined the drift matrix parameters in Table 3 and Figure 3c-d that illustrate the processes' cross effects. Results provide evidence in support of Hypothesis 4 and imply that social rank markedly increases an individual's prestige over time ($\bar{x} = 1.10, SD = 0.23, CI = [0.66,1.58]$), to a greater extent than prestige affects social rank (see above). On the other hand, the effect of social rank on dominance was negligible ($\bar{x} = -016, SD = 0.15, CI = [-0.11,0.47]$). As outlined above, both the between-subject correlations and diffusion matrix correlations between prestige and social rank were positively related, while the between-subject correlations and diffusion matrix correlations between dominance and social rank indicate little to no relationship. The results support our hypothesis suggesting that social rank only impacted an individual's future prestige, whilst it had no detectible effect on dominance.

6.4. Are prestige and dominance distinct temporal processes (H5)?

As shown in Table 2, prestige and dominance did not have a substantial correlation at any time point in the study. Both of these results are consistent with Hypothesis 5.

The drift parameters and diffusion matrix correlations between prestige and dominance assess the interrelatedness of changes in the processes over the observed time range, while the correlation between the average level of the processes points to their relation in a cross-sectional sense. As shown in Table 3 and Figure 3c-d, all such parameters include zero in the *CI*, providing evidence in support of Hypothesis 5 and suggesting that if there is a relationship between prestige and dominance, it is not as substantial as that between other processes discussed. Results support our hypothesis that, whilst prestige and dominance tended to have a negative impact on one another, the relationship was limited, and they may operate as independent processes.

7. Discussion

The current research extends prior work on human social hierarchy by proposing a theoretical account of how prestige and dominance fare over time. We also provide the first longitudinal empirical assessment of the hypothesised dynamic relationships. Through a longitudinal task-group design the present research examined the unique effects that prestige and dominance had on social rank from the initial formation of collaborative groups through to the completion of those group's tasks using an advanced analytical technique. In line with previous research (Cheng et al., 2013), results replicate that both prestige and dominance

coexisted as successful rank acquisition strategies in newly acquainted groups. These results align with previous work that suggests that humans have a predisposition to defer to those that they perceived as able and willing to either confer benefits or inflict harm, even among groups of undergraduate students, whereby fear and threat may not be particularly potent.

Critically, however, in the weeks following group formation, dominance did not have a substantial effect on social rank, whilst prestige strongly increased social rank over time. The present findings also demonstrated that the relationship that prestige had with social rank was bidirectional, with an individual's social rank having a positive temporal effect on prestige. Finally, results support the notion that prestige and dominance are distinct processes, with neither process having a substantial temporal impact on one another and random disturbances on the two processes having a limited correlation.

The current research highlights that time is of both theoretical and methodological importance in the assessment of processes relating to social hierarchy. The present findings supported the prestige-dominance account of human social hierarchy and further highlight the complexities of human rank attainment and maintenance over time. Specifically, we argue that in collaborative task-based groups, which is a widely generalizable context, there is a premium placed on prestige, such that prestige maintains an individual's social rank whilst social rank further increases their prestige. This relationship is important for the interpretation of cross-sectional assessments of the relationship between prestige and social rank. Cross-sectionally, a significant relationship between the two processes in previously acquainted groups is often interpreted as prestige impacting social rank. However, the present research highlights that these cross-sectional findings should be interpreted with caution as the converse relationship may in fact be what they are observing. The following section outlines

the broad implications of the current research for understanding social hierarchy and rank allocation in human groups.

7.1 Implications for the Dual Model of Social Hierarchy

The dual model of social hierarchy outlines that, in human hierarchies, individuals may attain social rank through prestige and dominance (Henrich & Gil-White, 2001). Expanding upon this, the current research provides a theoretical framework for the distinction between these two processes over time demonstrating that dominance and prestige have no substantial within-person temporal relationship or between-subject correlation throughout the period observed. This finding stands in contrast with the concept that social rank acquired through dominance is only made viable as the cues to dominance are misinterpreted by peers as indications of prestige-related traits, such as competence (Anderson & Kilduff, 2009b; Chapais, 2015; Lukaszewski et al., 2016). These results provide clear indication that dominant individuals are not simply confused as prestigious, neither concurrently nor over time. Rather, the current findings support that individuals in unacquainted groups may attain rank through two distinct, concurrent routes either centred on producing fear through aggression and coercion or obtaining respect through skill and competence (Cheng et al., 2013, 2010; Sijtsema, Veenstra, Lindenberg, & Salmivalli, 2009). Importantly, the present findings indicate that prestige and dominance have divergent temporal relationships with social rank, with prestige having a strong, positive and sustained relationship with social rank, whilst the effect that dominance has on rank attainment, in this context, is negligible over time.

The question raised by these results, therefore, is not *whether* dominance is a successful rank acquisition strategy but *when*. In which contexts and at what times in an interaction is dominance a viable route to acquiring and maintaining social rank? In the nascent stages of group formation, the context-dependent norms that constrain dominance may have limited potency for two reasons. Firstly, dominance-related traits and behaviours may be incredibly potent in newly-formed groups, signalling their threat potential and allowing them to acquire rank among unacquainted individuals who have limited cues to attend to (Bruckert, Liénard, Lacroix, Kreutzer, & Leboucher, 2006; Cheng et al., 2016; Farley, 2008; D. R. Feinberg, Jones, Little, Burt, & Perrett, 2005). Secondly, previous research has indicated that leveling mechanisms that may produce such context-dependent norms, for example coalitions, negative gossip and group sanctions, monitor behaviours and supress the relationship between dominance and social rank (Boehm, 2009; Dunbar, 1996; Feinberg, Willer, & Schultz, 2014). Unacquainted individuals do not have high degrees of relational closeness and may not be able to or feel comfortable to discuss an absent other as part of monitoring and gossip (Burt & Knez, 1996; Dunbar, 1996), thus the potency of these leveling mechanisms would be limited. The current research highlights that these norms may come into fruition only once individuals have become better acquainted and that suggests that the levelling mechanisms underlying such norms may explain the present finding that dominance is effective only in the initial period and not over the entire period of study. Directly assessing the emergence and success of a vast array of leveling efforts aimed at preventing coercive leadership, in order to understand why certain individuals manage to acquire and retain influence over time through force and fear and why some groups succeed (while others fail) in leveling dominance, remains an important and open area for future inquiry.

Antithetically, the present findings offer the first empirical evidence indicating that, whilst prestige is related to social rank among unacquainted individuals when groups initially form, this relationship remains strong over time. These results support the theoretical account outlining that prestige-based social rank may have developed dynamically alongside the remarkable capacity for cultural learning that humans exhibit, with cultural learning providing an opportunity for prestige-based rank and also being propagated by prestige (Boyd & Richerson, 1988; Henrich & McElreath, 2003). Among unacquainted individuals, those assessing who to learn from, and support or cooperate with, are relatively naïve and may attend to cues that are weakly associated to an individual's skill, knowledge and ability (Henrich, 2016). At the same time, dominance may operate effectively, with those high in dominance commanding the attention of others. However, once individuals collect more information about their peers over time, more robust impressions of an individual's prestige can form, which are based on repeated observations of cues to both their ability and to a cooperative, prosocial disposition. Moreover, the extremely high continuous-time between-subjects correlation and raw discrete-time correlations observed in the present study indicate that, over time, prestige and social rank become close to being indistinguishable. The current research suggests that, over time, individuals can more readily discern prestige, are more likely to confer deference and, thus, suggest an association between prestige and social rank becomes incredibly strong over time.

One of the hypothesized central cues to a potential learning model's prestige is the attention, deference and followership that they receive from proximate others (Henrich, Chudek, & Boyd, 2015; Henrich & Gil-White, 2001). Individuals with high social rank are likely to receive greater attention, deference and followership from their peers and, thus, an individual's social rank should have positive feedback into their prestige over time. The

present findings not only provide the first empirical evidence that prestige has a positive temporal effect on social rank, but that social rank also has a strong temporal effect on prestige, emphasizing that the relationship between prestige and social rank is dynamic and the processes may be mutually dependent. Taken together, the present findings suggest that, through this process, the dynamic relationship between prestige and social rank may be wedded together in human hierarchy, highlighting that over time prestige becomes incredibly potent and that social rank also increases an individual's prestige over time.

7.2 Limitations and future directions.

The present findings pose questions as to when exactly dominance is a viable pathway for both attaining and maintaining social rank, and further empirical investigation is needed to directly assess the mechanisms that may level dominance over time. Previous research outlining group mechanisms that level dominance has been theoretical (i.e. Boehm, 2009) and further research should directly test how the outlined mechanisms affect dominance over time, such as through gossip (Feinberg, Cheng, & Willer, 2012), coalitions (Fessler & Holbrook, 2013; Gintis et al., 2015) , and potentially the concurrent prestige effect (Chudek & Henrich, 2011; Henrich et al., 2015). Moreover, future research may assess the strategies that those high in dominance may implement to maintain their social rank in light of potential group leveling mechanisms. For example, there may be certain contexts where dominance fares well over time, such as when operating in dyads (Ridgeway, 2017); or when group size is large and relatively fragmented, and members share the diffused costs inflicted by dominant individuals and thus show a great willingness to tolerate them; when individuals have formalized power (Magee & Galinsky, 2008); when groups are directly competing

against neighboring others and dominance is potentially complemented by an individual's perceived competence in outcompeting or inflicting harm against the outgroup (i.e. Cheng et al., 2010; Halevy et al., 2008; Neave & Wolfson, 2003); or in groups where dominance-related traits are promoted by social norms (Henry et al., 2000; Redhead, 2016). Moreover, dominant individuals may attempt to ostracise their competition (Case & Maner, 2014), and may potentially modify the structure of a group so as to prevent group leveling mechanisms from having an impact on their position.

In terms of the modelling approach, while stable individual differences and common causes have been accounted for, reducing the possibility of spurious cross-effect results, with observational data causality is never clear. We cannot determine whether it is precisely changes in social rank that cause changes in prestige, or whether it is rather changes in something highly related to social rank. Moreover, the scales used to measure prestige, dominance and social rank were created and tested using a between-subjects application (Cheng et al., 2010). Future research assessing and validating the current scales and their within-subject temporal relationships would further disentangle how measures distinctly load onto the latent concepts of prestige, dominance and social rank.

A key limitation of the current research is the reliance on North American undergraduate students in assessing the proposed evolutionary framework. This population is often not representative of the world's populations (Henrich, Heine, & Norenzayan, 2010). Whilst there has been previous research assessing the effects of prestige and dominance on rank attainment a number of populations, such as the Tsimane of Bolivia (von Rueden et al., 2010), the Chabu of Ethiopia (Garfield & Hagan, Under Review), in a developmental setting in rural Romania (Redhead, 2016) and the United States and Canada (Cheng et al., 2013,

2010; Johnson, Burk, & Kirkpatrick, 2007), all studies have been cross-sectional. Thus, despite an important advantage of providing larger sample sizes for more accurate parameter estimates and the ability to track groups from the point of their formation, the current task-group setting potentially limits the processes discussed to the dynamic relationship between prestige, dominance and social rank to task-groups in WEIRD settings or to these processes during young adulthood.

Future research investigating the temporal dynamics of prestige, dominance and social rank is needed on a broader timescale that encompasses multiple ages among geographically and culturally diverse societies to further generalize how effective both routes are for attaining and maintaining social rank in human groups and ascertain when dominance becomes a long-term strategy for maintaining social rank. Through this, such future research may further capture the effects of prestige and dominance in different tasks over time and further measure dominance in contexts where aggression is potent and more dramatic displays of dominance and aggressive intent may be observed. Future research may also provide a further understanding of the generalizability of the present results over a longer timescale, as multiple observations spanning years may exhibit less temporal stability than that observed in the current design.

Conclusion.

In conclusion, the current research provides the first empirical assessment of the longitudinal relationships between prestige, dominance and social rank. The present findings offer support for both dominance and prestige being effective in initial rank attainment but suggest that only prestige is an effective process for maintaining social rank over time.

Moreover, the current research delivers considerable insight—both theoretically and methodologically—into the complex temporal dynamics of prestige, dominance and social rank by presenting and substantiating a longitudinal framework for understanding human social hierarchy.

Equations

Equation 1. Matrix specification of the subject-level model for the relationships between social rank, dominance and prestige. Notations that are underbraced represent both the matrix name specified in the ctsem model and also the symbol used in formulas outlined in Driver & Voelkle (2018).

$$\underbrace{d\begin{bmatrix}\eta_1\\ \eta_2\\ \eta_3\end{bmatrix}(t)}_{\mathrm{d}\boldsymbol{\eta}(t)} = \left(\underbrace{\begin{bmatrix}\text{drift\_socialRank\_socialRank} & \text{drift\_dominance\_socialRank} & \text{drift\_prestige\_socialRank}\\ \text{drift\_socialRank\_dominance} & \text{drift\_dominance\_dominance} & \text{drift\_prestige\_dominance}\\ \text{drift\_socialRank\_prestige} & \text{drift\_dominance\_prestige} & \text{drift\_prestige\_prestige}\end{bmatrix}}_{\underset{\text{DRIFT}}{\mathbf{A}}}\underbrace{\begin{bmatrix}\eta_1\\ \eta_2\\ \eta_3\end{bmatrix}(t)}_{\eta(t)} + \underbrace{\begin{bmatrix}0\\0\\0\end{bmatrix}}_{\underset{\text{CINT}}{\boldsymbol{b}}}\right)dt +$$

$$\underbrace{\begin{bmatrix}\text{diffusion\_socialRank\_socialRank} & 0 & 0\\ \text{diffusion\_socialRank\_dominance} & \text{diffusion\_dominance\_dominance} & 0\\ \text{diffusion\_socialRank\_prestige} & \text{diffusion\_dominance\_prestige} & \text{diffusion\_prestige\_prestige}\end{bmatrix}}_{\underset{\text{DIFFUSION}}{\boldsymbol{G}}}\underbrace{\mathrm{d}\begin{bmatrix}W_1\\ W_2\\ W_3\end{bmatrix}(t)}_{\mathrm{d}\mathbf{W}(t)}$$

$$\underbrace{\begin{bmatrix}Y_1\\ Y_2\\ Y_3\end{bmatrix}(t)}_{\mathbf{Y}(t)} = \underbrace{\begin{bmatrix}1 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 1\end{bmatrix}}_{\underset{\text{LAMBDA}}{\boldsymbol{\Lambda}}}\underbrace{\begin{bmatrix}\eta_1\\ \eta_2\\ \eta_3\end{bmatrix}(t)}_{\boldsymbol{\eta}(t)} + \underbrace{\begin{bmatrix}\text{manifestmeans\_socialRank}\\ \text{manifestmeans\_dominance}\\ \text{manifestmeans\_prestige}\end{bmatrix}}_{\underset{\text{MANIFESTMEANS}}{\boldsymbol{\tau}}} + \underbrace{\begin{bmatrix}\epsilon_1\\ \epsilon_2\\ \epsilon_3\end{bmatrix}(t)}_{\boldsymbol{\epsilon}(t)}$$

$$\underbrace{\begin{bmatrix}\epsilon_1\\ \epsilon_2\\ \epsilon_3\end{bmatrix}(t)}_{\boldsymbol{\epsilon}(t)} \sim \mathrm{N}\left(\begin{bmatrix}0\\0\\0\end{bmatrix}, \underbrace{\begin{bmatrix}\text{manifestvar\_socialRank\_socialRank} & 0 & 0\\ 0 & \text{manifestvar\_dominance\_dominance} & 0\\ 0 & 0 & \text{manifestvar\_prestige\_prestige}\end{bmatrix}}_{\underset{\text{MANIFESTVAR}}{\Theta}}\right)$$

Tables

Table 1.
Descriptive statistics for all variables.

Variable	*n*	Mean (*SD*)	Median	Min	Max
Prestige *T*1	259	5.04 (0.76)	5.06	2.36	7.00
Prestige *T*2	256	4.87 (1.00)	4.88	1.00	7.00
Prestige *T*3	250	5.03 (1.04)	5.08	1.25	7.00
Prestige *T*4	249	5.09 (1.07)	5.17	2.00	7.00
Dominance *T*1	259	2.80 (0.62)	2.75	1.62	5.50
Dominance *T*2	256	2.64 (0.85)	2.62	1.00	6.00
Dominance *T*3	250	2.68 (0.94)	2.62	1.00	6.50
Dominance *T*4	249	2.61 (0.96)	2.62	1.00	5.62
Social Rank *T*1	259	4.56 (0.93)	4.67	1.83	6.67
Social Rank *T*2	256	4.63 (1.00)	4.82	1.00	6.79
Social Rank *T*3	250	4.90 (0.98)	5.08	1.17	7.00
Social Rank *T*4	249	4.95 (0.94)	5.00	2.25	6.92
Gender [a.]	262	0.60 (0.49)	-	0.00	1.00

Note. $N = 263$.
Total percentage of missing data = 14.54%.
a. Males were coded 0, females coded 1.

Table 2.
Bayesian correlations between prestige, dominance and social rank.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1.Social Rank T_1	[a] .71	-	-	-	-	-	-	-	-	-	-	-
2.Social Rank T_2	0.66**	[a] .79	-	-	-	-	-	-	-	-	-	-
3.Social Rank T_3	0.58**	0.71**	[a] .74	-	-	-	-	-	-	-	-	-
4. Social Rank T_4	0.48**	0.66**	0.77**	[a].68	-	-	-	-	-	-	-	-
5.Dominance T_1	0.20*	-0.00	-.05	-0.07	[a] .82	-	-	-	-	-	-	-
6. Dominance T_2	0.27**	0.14	0.06	0.07	0.52**	[a] .86	-	-	-	-	-	-
7.Dominance T_3	0.20*	0.16	0.10	0.09	0.49**	0.63**	[a] .91	-	-	-	-	-
8. Dominance T_4	0.19*	0.19*	0.04	0.06	0.46**	0.60**	0.65**	[a] .93	-	-	-	-
9. Prestige T_1	0.38**	0.31**	0.35**	0.32**	-0.11	-0.04	-0.07	-0.13	[a] .88	-	-	-
10. Prestige T_2	0.48**	0.84**	0.64**	0.57**	-0.09	-0.03	0.04	0.06	0.40**	[a] .89	-	-
11. Prestige T_3	0.45**	0.67**	0.82**	0.68**	-0.18	-0.03	-0.05	-0.02	0.38**	0.73**	[a] .88	-
12. Prestige T_4	0.43**	0.64**	0.70**	0.80**	-0.15	0.04	-0.05	-0.02	0.30**	0.67**	0.80**	[a].90

Note. $N = 263$
*BF_{10} > 10 **BF_{10} >100. Bayes Factor (BF) assesses the relative predictive performance of the alternative hypothesis (H_1) compared to the null hypothesis (H_0) by restricting the prior distribution of ρ under H_0 to zero, whilst relaxing the restriction for ρ under H_1 (Marsman & Wagenmakers, 2017).
[a] Cronbach's Alpha (α) reliabilities.

Table 3.
Means, standard deviations and posterior credibility intervals (*CI*) for means of estimated population distributions.

	Dependent Process								
	Social Rank			Dominance			Prestige		
Parameter	$\bar{x}$	*SD*	*CI* *[2.5%, 97.5%]*	$\bar{x}$	*SD*	*CI* *[2.5%, 97.5%]*	$\bar{x}$	*SD*	*CI* *[2.5%, 97.5%]*
T_0 Mean	-0.66	0.57	[-1.46, 0.85]	0.19	1.20	[-1.54, 3.72]	-0.82	0.54	[-1.73, 0.65]
Manifest Means	5.13	0.58	[3.60, 5.93]	2.53	1.20	[-1.01, 4.24]	5.34	0.54	[3.89, 6.25]
Manifest Variance	0.28	0.06	[0.13, 0.36]	0.47	0.04	[0.38, 0.54]	0.25	0.10	[0.02, 0.38]
Main Effect of Gender [a]	0.14	0.10	[-0.05, 0.32]	-0.13	0.09	[-0.30,0.04]	0.14	0.10	[-0.60, 0.33]
Between-subject Parameters [b]									
Social Rank	-	-	-	-	-	-	-	-	-
Dominance	-0.02	0.20	[-0.48, 0.31]	-	-	-	-	-	-
Prestige	0.78	0.12	[0.42, 0.90]	-0.28	0.24	[-0.81, 0.17]	-	-	-
Drift Parameters									
Social Rank	-0.66	0.19	[-1.07, -0.32]	0.16	0.15	[-0.11, 0.47]	1.10	0.23	[0.66, 1.58]

Dominance	0.12	0.12	[-0.09, 0.38]		-0.23	0.16	[-0.59, -0.02]	-0.20	0.16	[-0.50, 0.11]
Prestige	0.33	0.15	[0.05, 0.66]		-0.05	0.13	[-0.31, 0.20]	-1.07	0.22	[-1.52, -0.66]
Diffusion Parameters										
Social Rank	0.62	0.07	0.50	0.79	-	-	-	-	-	-
Dominance	-0.03	0.12	-0.25	0.20	0.50	0.11	[0.32, 0.74]	-	-	-
Prestige	0.71	0.12	0.46	0.90	-0.22	0.18	[-0.60, 0.14]	0.74	0.11	[0.55, 0.94]

Note. n = 263. $T = 4$.

[a.] Gender was coded 0 for males and 1 for females. Thus, a positive parameter indicates that being female had a positive main effect on the process, whilst a negative parameter would suggest that being male had a positive effect on the process.

[b.] Between-subject parameters are the standardized population correlations.

Figures

Figure 1. A triadic (three-process) continuous time structural equation model. The model comprise
(dominance, social rank and prestige) and one time-independent predictor (gender). Black circles i
continuous time processes that load onto the 3 manifest variables. Regression paths are solid black
or processes, variance/covariance paths are dashed black lines between variables or processes and
represent those constrained to a function of other parameters. Manifest intercepts are not represe
D = Dominance
Gen = Gender
P = Prestige
SR = Social Rank

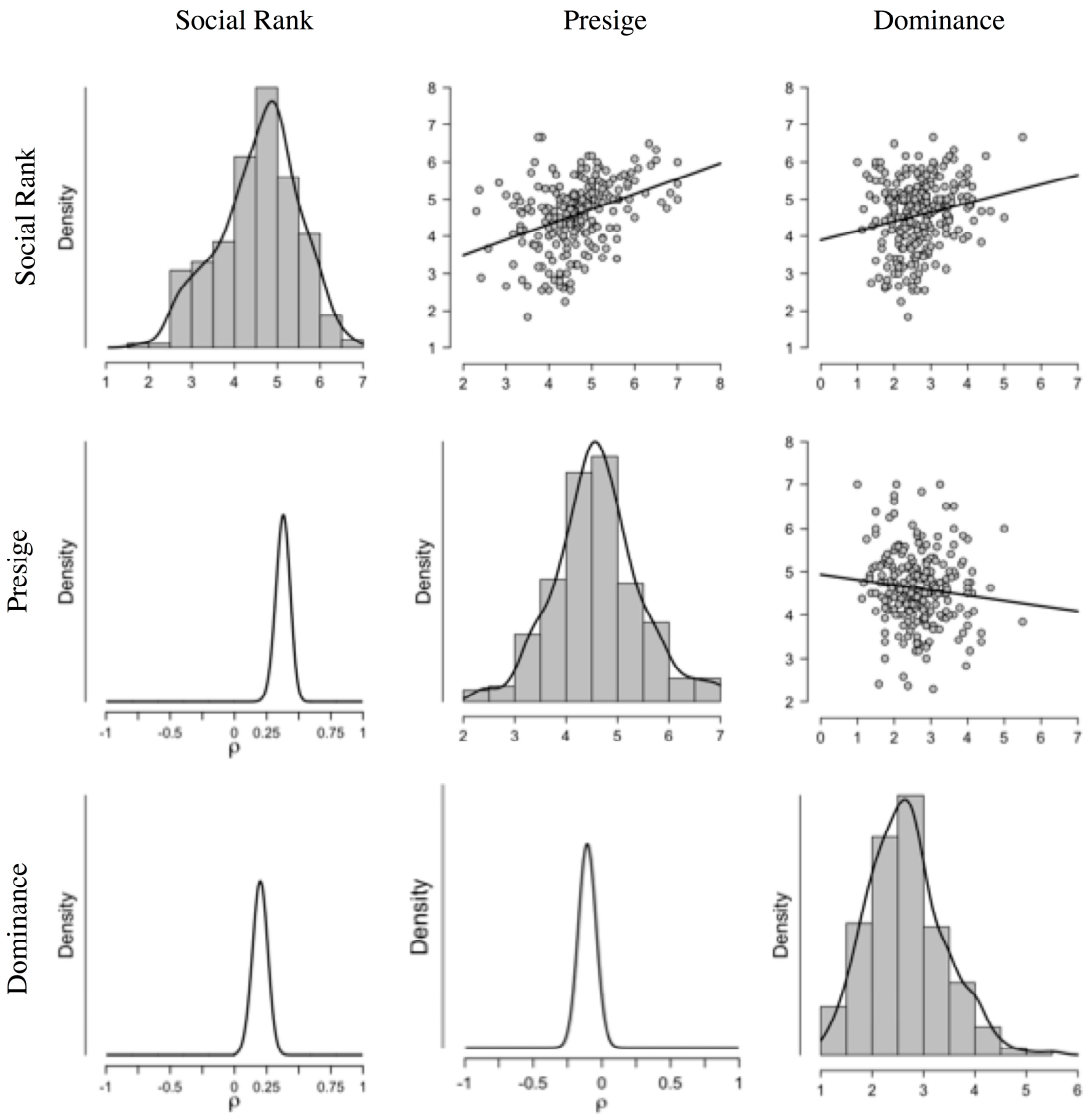
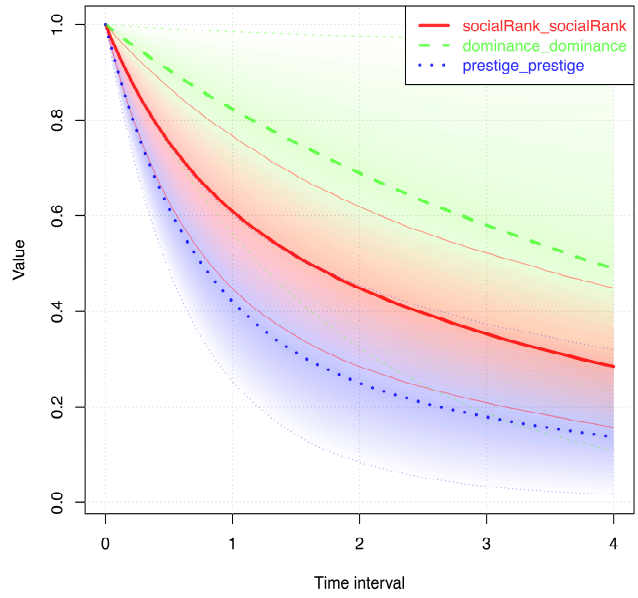
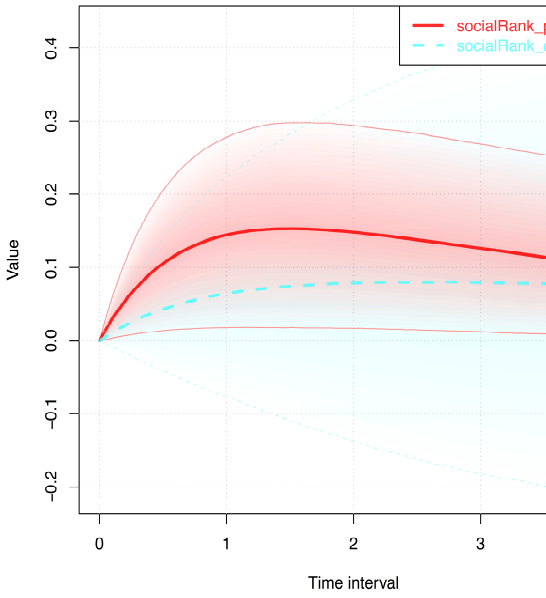
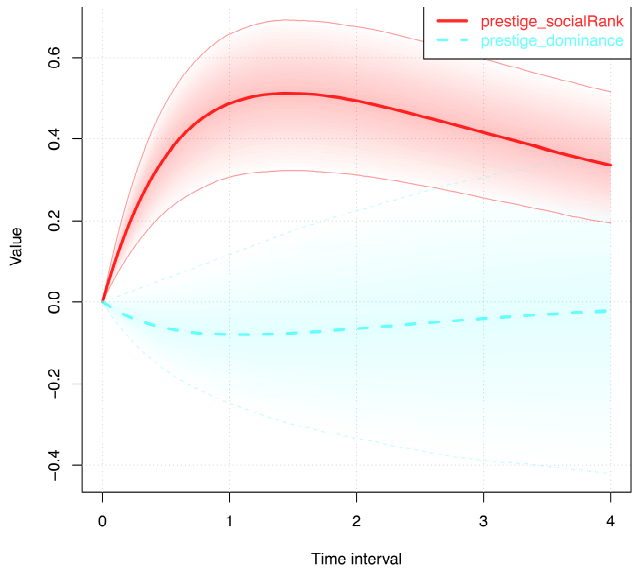
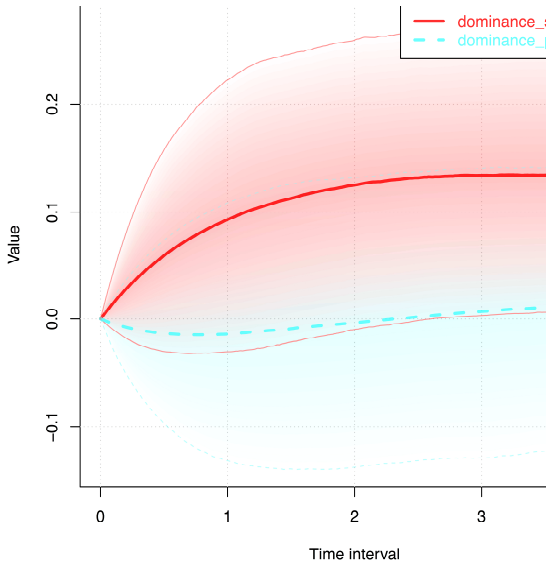

Social Rank
Presige
Dominance
Social Rank
Presige
Dominance
Density
ρ

Figure 2. Correlation plots, variable densities and posterior densities between social rank, prestige and dominance in the initial time wave.


socialRank_socialRank
dominance_dominance
prestige_prestige
Value
Time interval


socialRank_
socialRank_
Value
Time interval


prestige_socialRank
prestige_dominance
Value
Time interval


dominance_
dominance_
Value
Time interval

a.

b.

c.

d.

4

The structure of social hierarchy

4.1. Introduction

The current research proposes that social hierarchy is a complex dynamic system that is embedded in the social networks in which humans operate. Social networks are patterns of interpersonal relationships, operationalized as ties between a group of people, termed nodes or actors (Wasserman & Faust, 1994). This approach to understanding social relationships provide a foundation for understanding social interdependence—both theoretically and analytically—in assessing social and relational processes (Borgatti, Mehra, Brass & Labianca, 2009; Sniders, 2016). These webs of interpersonal relationships are dynamic and change over time through processes endogenous to the networks and through exogeneous processes associated with an individual's personal characteristics and attributes (Snijders, 2001; Snijders, Steglich & Van De Bunt, 2010). Changes in such relationships may be as much as cause of changes as a consequence of changes related to social hierarchy (Carter et al., 2015; Torló & Lomi, 2017).

A growing body of cross-sectional evidence from human social hierarchies has suggested that prestige—a profile centred on an individual's ability and willingness to confer benefits to others—and dominance—a profile linked with the ability and willingness to inflict harm on others—predict social rank in an array of settings (Cheng et al., 2013; Garfield & Hagan, in press; Henrich & Gil-White, 2001; Redhead, 2016; Von Rueden et al., 2010). However, given the complex relational and hierarchical systems in which humans operate, the strengths of the relationships that these profiles have with social rank vary over context and potentially over time. The present research utilizes a longitudinal network dynamics approach to assess the

potentially bidirectional relationships between prestige, dominance and social networks.

4.1.1. The Dual Model of Social Hierarchy

Social hierarchy is a universal phenomenon among human groups (Brown, 1991; Mazur, 1985). The differentiation of social rank—defined as an individual's relative position within a social hierarchy based on their social influence and agency (Anderson & Kilduff, 2009a; Báles, Strodtbeck, Mills & Roseborough, 1951; Berger, Rosenholtz, Morris & Zelditch, 1980; Henrich & Gil-White, 2001)—forms spontaneously and develops informally in groups (Hollander, 1945) and the desire to attain positions of high social rank is believed to be a fundamental human motive (Alexander, 1979; Anderson et al., 2015; Barkow, 1975).

Across environments, individuals attain high social rank through two distinct profiles: dominance and prestige (Henrich & Gil-White, 2001). Those high in dominance are habitually aggressive, narcissistic and extraverted, and harness social rank through fear, coercion and manipulation (Chance, 1967; Cheng, Tracy & Henrich, 2010; Henrich & Gil-White, 2001). This fear is produced through these traits signalling an ability and willingness to inflict harm on others. Dominance may have evolved alongside hubristic pride (Cheng, Tracy & Henrich, 2010). Hubristic pride is marked by arrogance, conceit, lack of conscientiousness and an inability to form and maintain stable interpersonal relationships (Tracy et al., 2009). Individuals high in dominance appropriate social rank, with individuals conferring deference in an attempt to lessen the costs imposed by them (Henrich & Gil-White, 2001). Empirical evidence indicates that individuals attain social rank through dominance in

unacquainted groups (Cheng et al., 2013; Redhead et al., under review), in developmental settings (Redhead, 2016; Redhead et al., 2018), and in some small-scale societies (Garfield & Hagan, under review; Konecna & Urlacher, 2017; Von Rueden et al., 2010).

Unlike dominance, the social rank of those high in prestige is granted by group members through freely-conferred deference. The traits that comprise a prestige psychological profile signal an individual's ability and willingness to confer benefits to others. Individuals high in prestige often express high levels of genuine self-esteem, extraversion, agreeableness and conscientiousness (Cheng, Tracy & Henrich, 2010), and the traits that these individuals harbour rouse respect and admiration from others (Anderson et al., 2001; Blau, 1964; Cheng, Tracy, Henrich, 2010; Henrich & Gil-White, 2001; Krackhardt, 1990; Ridgeway & Diekema, 1989). Prestige is associated with authentic pride, which drives achievement-oriented motivations and promotes a prosocial disposition (Ashton-James & Tracy, 2012). Evidence from a diverse range of societies indicates that those high in prestige are conferred deference as they can provide inalienable goods of value to the group, which promote coordination, cooperation and social learning and, thus provide net benefits to the group (Cheng et al., 2013; Garfield & Hagan, under review; Henrich & Gil-White, 2001; Lewis, 2002).

4.1.2 A network dynamics approach to understanding social hierarchy

Human social life is structurally patterned (Kilduff, Tsai, & Hanke, 2006; Wasserman & Faust, 1994). Human behaviours are embedded within networks of interpersonal relationships (Granovetter, 1985), which are principal elements in defining the identities of individuals (Kilduff & Tsai, 2003), govern individual

positions within a group (Torlò & Lomi, 2017), and provide benefits to both individuals and groups that have been fundamental to human evolution (Ohtsuki, Hauert, Lieberman, & Nowak, 2006). The characteristics of human social networks have been attributed to our success as a species, as they seem to facilitate cooperation among kin and non-kin (Apicella, Marlowe, Fowler, & Christakis, 2012; M. A. Nowak, 2006b).There are several structural processes have been shown to lead to the emergence of interpersonal relationships across a diverse range of human groups, indicating that the observed regularities in social networks between societies may tackle problems faced throughout human evolution. More specifically, humans tend to reciprocate positive relationships, which facilitates cooperation (Boyd & Richerson, 1988) and form transitive groups (i.e. friends of friends become friends), which promotes trust and facilitates social norm reinforcement (Coleman, 1988). Connected individuals also exhibit behavioural and attitudinal similarity (McPherson, Smith-Lovin & Cook, 2001), and further foster cooperation (Henrich, Chudek & Boyd, 2015). Certain individuals also seem to be more central to these networks of relations, whereas others remain on the periphery of the structure, which may reflect the inherently hierarchical nature of human groups and enable effective group coordination (von Rueden & van Vugt, 2015).

These social networks—while following many generalizable patterns—are dynamic, with the positions of individuals and the overall network structures exhibiting relative plasticity over time and context (Adams & Blieszner, 1994; T. A. Snijders, 2001). Human social networks are complex systems that are multi-level in nature (Snijders, 2016). For example, in contemporary organizations, workers often comprising autonomous task-based teams that form that form the larger company, and small-scale societies are collections of individuals that are nested in families of

consanguineal and affinal kin, which further comprise larger groups of distantly related individuals (i.e. Blurton-Jones, 2000; Chagnon, 2012). Differences in network structures likely emerge in response to both the organizational needs of a group (Carter et al., 2015) and the ecological pressures and constraints that a group faces (Hamilton, Milne, Walker, Burger, & Brown, 2007). Evidence indicates that the structure and size of hunter-gatherer social networks adjust to accommodate spatial and temporal fluctuations in the distribution of available resources (Hamilton et al, 2007). Moreover, in contemporary societies, leader-follower team structures exhibit different levels of density, centralization and core-periphery structures between tasks and further impact team group performance and efficiency (Balkundi & Harrison, 2006; Mehra, Dixon, Brass, & Robertson, 2006). It seems that the social networks in which human are relatively stable, however they are dynamic and display flexibility to accommodate the group needs.

Social networks are the dynamic social systems in which social hierarchy operates. Social hierarchy is inherently relational (Carter et al., 2015; DeRue & Ashford, 2010). The structural properties of these systems govern who rises to the top of a social hierarchy by constraining or facilitating an individual's ability to act, and also signpost the social influence that individuals harness within a group (Balkundi & Kilduff, 2006). Networks create power, with ties between individuals creating flows and exchanges of resources and information that produce social capital. Thus, greater centrality within these networks may be beneficial for both an individual's social rank (Burt, 1982; Coleman, 1988; Cook, Emerson, Gillmore, & Yamagishi, 1983; Lazega, Mounier, Snijders, & Tubaro, 2012; Sparrowe, Liden, Wayne, & Kraimer, 2001) and further increase the overall fitness of groups (Boyd & Richerson, 2005; D. S. Wilson, 1998).

Expressive ties result in positive affect, which promotes social and emotional support, indicate normative behaviours and provide a sense of identity for those involved (Coleman, 1988). Being central, and occupying strategic positions, within these networks—especially friendship—allows individuals to harness greater social influence, control information exchange within their groups and have improved well-being and longevity(DeScioli & Kurzban, 2009; Holt-Lunstad, Smith, & Layton, 2010; Hruschka, 2010; Li & Kanazawa, 2016). Such expressive ties are also usually stable among non-human primates and have also been linked to success of certain individuals within their groups (Seyfarth & Cheney, 2011).

We propose that instrumental and expressive network ties form two components of human cooperation, and these ties have important consequences for the success of prestige and dominance in human groups. Instrumental network ties are forms of cooperative behaviours, such as food-sharing, advice-giving and labour-sharing, that are integral to the striking interdependence that characterizes human groups (Henrich & Gil-White, 2001; Winterhalder, 1986). Expressive ties facilitate these cooperative acts and are antecedents of instrumental ties. For example, individuals are more likely to deliver advice to and share resources (i.e. instrumental ties)—and reciprocate such acts—with the friends (i.e. expressive ties) that they have within a group (Majolo, Lehmann, de Bortoli Vizioli, & Schino, 2012; Trivers, 1971). Concurrently, instrumental ties may forecast expressive ties, with, for example, instrumental advice being found to lead to friendships (Snijders, Lomi & Torló, 2013) and cross over to more expressive areas of advice, such as emotional support. Therefore, the longevity of cooperative relationships may have emerged alongside the multiplexity and coevolution of instrumental and expressive networks within human

groups. That is, instrumental ties of cooperation are as much a consequence, as they are a cause of, concurrent networks expressive ties.

Prestige, instrumental and expressive network ties. Prestige has been linked with fostering group cooperation and cohesion (Barkow, 2014; Henrich, Chudek & Boyd, 2015; Henrich & Gil-White, 2001; Von Rueden, Redhead et a., in prep). With that in mind, prestige is likely to have a positive connection with both instrumental and expressive network ties. The association between prestige and the plethora of instrumental ties is founded by the central notion that prestige is associated with social learning (Henrich & Gil-White, 2001). Thus, those high in prestige, who cue both an ability and a willingness to confer benefits to others, may be nominated as providing some form of instrumental support as individuals aim to gain proximity, gleam knowledge from them and have access to the resources that these successful individuals may harbour (Henrich & Gil-White, 2001; Rossman, Esparza, & Bonacich, 2010). Within this exchange, those high in prestige receive deference. For the lower-prestige counterpart, the ties operated as an avenue for them to improve their social position and increase their own prestige over time.

The dynamics of this relationship may also provide further benefits to those already high in prestige. Individuals cannot maintain such instrumental relationships over time without having the correct knowledge or appropriate skills that the current context may demand, so it becomes improbable for individuals feigning such ability associated with prestige to sustain such ties (Gintis, Alden Smith, & Bowles, 2001; Gintis et al., 2015; Zahavi, 1977). While an individual who is high in prestige may attract more incoming ties, the presence of those ties are important signals to

proximate others of that individual's ability and willingness to confer benefits and are therefore likely to increase the individual's perceived prestige.

Given this potentially dynamic association, it is likely that those high in prestige may also be less likely to seek others for instrumental support, as this may signal an inability to confer benefits to others and have a deleterious impact on their perceived prestige (Agneessens & Wittek, 2012), but may reciprocate the relationship indirectly, through other, potentially expressive, ties that may secure the longevity of the cooperative relationships. That being said, there is an element of stochasticity in relation to human need and humans are highly interdependent, with individuals needing to buffer against potential losses caused by sickness (i.e. Gurven & Kaplan, 2007). Therefore, it is important to stress that different forms of instrumental ties and expressive ties may have greater weighting for survival, giving greater premium to direct reciprocity, and those high in prestige will also receive instrumental support over a given timeframe. However, those high in prestige will not seek instrumental support but may be less likely to need—and thus ask for—instrumental support and, thus, on average, prestige would not have a positive relationship with outgoing instrumental support nominations.

As expressive ties facilitate the longevity of instrumental ties, prestige is predicted to have a positive relationship with both sending and receiving expressive ties. Indeed, the personality correlates of prestige (i.e. agreeableness) have been found to predict incoming friendship ties (Selfhout et al., 2010) and the prosocial disposition that individuals high in prestige harbour make them more likable (Cheng et al., 2013), suggesting that prestige would have a positive impact on expressive ties. Experimental evidence further lends support for the association that prestige has with

expressive ties, such as friendship, with individuals seeming to preferentially choose social partners who exhibit an ability and a willingness to confer benefits to others (Barclay, 2013; Barclay & Willer, 2009). Concurrently, these expressive ties may also act as relatively weak signals to an individual's prestige and incoming ties may further increase an individual's prestige.

Alongside this, the potential similarity between connected individuals based on prestige may be a product of network influence (i.e. behavioural similarity between individuals due to network ties: Steglich, Snijders, & West, 2006; Steglich et al., 2010), as opposed to network selection (i.e. initial trait-based homophily: McPherson et al., 2001. Networks of relationships concurrently influence social rank, with social rank seeming to be contagious and diffusing through ties between low-ranking and high-ranking conspecifics (Kilduff & Krackhardt, 1994; Podolny, 2001; Torlò & Lomi, 2017). This relationship is expected for prestige as there is market-like competition between those high in prestige for followers low in prestige and, thus, also competition between those low in prestige to gain proximity to their high-prestige counterparts.

Dominance, instrumental and expressive network ties. Dominance is expected to have an entirely different association with both expressive and instrumental ties. Those high in dominance are characterized as being aggressive, antisocial, narcissistic and high in hubristic pride (Cheng et al., 2010), and these traits are not positively related with choice in social partners during adulthood (Barclay, 2013), nor with a motivation to provide instrumental support (Henrich & Gil-White, 2001). Moreover, dominance has a negative relationship with cooperation (Cheng et al., 2010), with those high in dominance potentially undermining the cohesive fabric of groups to keep hold of their position (Case & Maner, 2014). Therefore, in many

contexts, dominance is hypothesised to have a negative impact on expressive ties that promote positive affect and with instrumental support. Those high in dominance are not expected to seek social relationships and, given the antisocial characteristics of the profile, are likely to be unable to maintain social relationships and, over time, may be less socially accepted (Cheng & Tracy, 2014). Moreover, dominance is not associated with a lack of skills or knowledge, and those high in dominance are not expected to be less able that there low-dominance counterparts; thus, a lack of instrumental support nominations should not be based on inability. Rather, dominance is expected to be ether unrelated or negatively to instrumental support as it is not contingent on advice-giving ability and is associated with a lack of motivation to help others (Cheng, Tracy & Henrich, 2010; Henrich & Gil-White, 2001)

In settings where an individual high in dominance may wield enough structural power within a network, dominance may be positively associated with expressive ties. Such settings may be where those high in dominance can successfully produce fear and disproportionate control over resources (i.e. in formalized hierarchies where communication, resource flow and power come from the top: Magee & Galinsky, 2008). Other settings may be when dominance is not actively sanctioned by social norms, for example in delinquent gangs (Henry et al., 2000; Pandit & Van Shaik, 2003; Redhead, 2016), or when groups are transient and do not display the levels of cohesion to facilitate coalition formation that levels dominance (Boehm, 1999; Case & Maner, 2014; Pellegrini & Long, 2003). In such situations dominance may be associated with expressive ties that promote positive affect, such as friendship, alliances or coalitions that act as strategic relationships for others to reduce the costs that an individual high in dominance is willing to inflict. For example, evidence from developmental psychology suggests that during childhood

and adolescence indicates that antisocial, egocentric, relationally aggressive individuals and bullies receive relatively high numbers of friendship nominations and have high social rank, although they are not liked (Hawley, 1999; Pellegrini & Long, 2003; Redhead, Cheng & O'Gorman, 2018; Sijstema et al., 2009). Thus, the success of dominance in human social networks may be constrained to a minority of situations where expressive ties are not associated with cooperation but are forged through fear.

Additionally, an individual's dominance may be differentially impacted by expressive and instrumental networks. Given the relationship that these ties have with cooperation, and that these ties may honestly signal prestige, incoming expressive and instrumental ties are expected to reduce an individual's perceived dominance. Similarity in dominance between individuals may be a product of both network selection and network influence, with individuals potentially initially seeking those of a similar level in dominance, as individuals low in dominance may fear high-dominance counterparts and avoid making connections with them. Network influence may further spread dominance between connected individuals, as individuals tend to mimic the behaviours of friends. For example, evidence suggests that, during adolescence an individual's centrality within friendship networks has a curvilinear relationship with aggression, highlighting that aggression may be most common during status struggles (Faris & Felmlee, 2011), and that the average levels of aggression that individual's friends display increases an individual's exhibited level of aggression (Faris & Felmlee, 2011; Laninga-Wijnen et al., 2017).

4.1.3 Overview of the current research

Extending on previous work outlining that social rank has a dynamic relation with social networks (Torló & Lomi, 2017), the current research proposes that *changes* in perceptions of prestige and dominance have bi-directional relationships with *changes* in the social networks that these individuals are embedded. The present research utilizes a longitudinal approach to parse network-based selection and network influence, which are often confounded in cross-sectional observational networks (Aral, Muchnik, & Sundararajan, 2009; Steglich et al., 2010) and further assesses the associations that changes in prestige and dominance have with changes across multiple network domains (Snijders, Lomi & Torló, 2013; Torló & Lomi, 2017).

To assess predicted associations that prestige and dominance have with network dynamics, we designed a longitudinal study that tracked university students working in collaborative task-based groups throughout a 16-week semester. These groups are a fruitful platform for investigation as they provide a fixed boundary of actors (i.e. classrooms) within organic, informal hierarchies. This allowed us to track the same individuals from the initial formation of the group to the end of their assigned projects. Such groups are reflective of the structure of contemporary organizations and of the collaborative decision-making processes that represent how many impactful decisions are made in contemporary societies (Anderson & Kilduff, 2009; Ridgeway & Berger, 1986; Ronay et al., 2012).

We propose three overarching hypotheses:

1.) Expressive and instrumental networks have emerged, with both networks bidirectionally impacting one another and facilitating the longevity of cooperation.

2.) Prestige will have a strong, bi-directional and positive (true?) relationship with both expressive and instrumental ties.

2.) Dominance will have a negative impact on expressive ties in most contexts and will have a limited association with instrumental ties.

See Table 1 for our specific predictions relating to these hypotheses.

4.2. Method

Participants. Using the same sample as Study 1 (see Chapter 3), students (*N*=236, 63% female) at a North American university participated in exchange for course-credit. Throughout the study participants worked in the task groups to complete a course project throughout the 16-week semester worth 30% of their final grade.

4.2.2. Procedure. Data were collected from two cohorts of students enrolled in a 16-week semester course over two years. Per week, participants attended a large lecture for two hours and spent a further four hours working in their randomly-assigned task groups in laboratory sections. Online surveys were administered in monthly intervals over the semester, with participants completing a self-report questionnaire in Week 1. Following this, participants met their group members and completed four self- and peer-report questionnaires during Week 2, Week 6, Week 10 and Week 16 of the semester. There were an extra two weeks between the administration of the fourth (Week 10) and fifth (Week 16) questionnaires to account

for the week-long holiday and mid-term exams during this period. Participants were assigned a unique ID and were allotted up to 7 days to complete each questionnaire using online survey tool Qualtrics.

Measures.

Task group. The course instructor provided information about the task groups that participants were nested in. Altogether there were 66 randomly assigned mixed-sex task groups, which each had between 3-5 members ($\bar{x} = 4.02, SD = 0.33$).

Gender. Participants reported the gender that they identify as during the self-report questionnaire at the beginning of the study (week 1). Participants were given the choice of 4 categories: 'male', 'female', 'neither male nor female' and 'prefer to not say'.

Prestige and dominance. Throughout the peer-report questionnaires (weeks 2, 6, 10, 16), participants rated all other members of their task groups on prestige and dominance, using an abridged version (in order to reduce participant fatigue) of the Prestige and Dominance Scaled Questionnaires (Cheng et al., 2010). All ratings were made on a scale ranging from 1 (*Strongly Disagree*) to 7 (*Strongly Agree*). Ratings comprised four items assessing perceived prestige (e.g. "*Their unique talents and abilities are recognized by others in the group*") and four items measuring perceived dominance (e.g. "*They enjoy having control over other members of the group*"). Ratings were then averaged at each time wave to obtain an overall prestige and overall dominance score for each participant. To achieve the data requirements for analysing dependent 'behaviors' in in the current analytical strategy (See Ripley et al.

2018), the continuous prestige and dominance composite scores were transformed into ordinal percentile rank scores with 10 levels that were approximately evenly distributed, with 1 encompassing the lowest scorers (the 10^{th} percentile) and 10 the highest scorers (the 90^{th} percentile). See Table 7 for descriptive statistics for all variables. Both prestige and dominance had excellent reliability, with $\alpha > .80$ at every time point (see supplementary materials for internal consistency at each time point).

Friendship networks. To construct sociocentric networks capturing friendships over the course of the semester, participants were asked to freely nominate the peers within the class who they "*considered to be their friends*". Although the method does not measure actual observed behavior, we opted for this name generator approach as it has been shown to produce reliable estimates of behaviors (i.e Coie, Dodge, & Coppotelli, 1982). To improve ecological validity of the measure, participants were free to nominate any other member of their respective cohort and, to reduce recall-accessibility bias, an alphabetical list of all participants' forenames and surnames were provided. Nominations between peers were coded 1, with non-nominations coded 0, and non-nominations due to non-responses coded as NA. Nomination data were specified as directed adjacency matrices for all four timewaves capturing friendship and contained all friendship nominations within the sample. See Table 5 for descriptive statistics.

Work-related (instrumental) advice networks. Networks were constructed by participants freely nominating peers within the class who they were *"most likely go to for advice and support on assignments and coursework"*. Again, to improve ecological validity of the measure, participants were free to nominate any other

member of their respective cohort and, to reduce recall-accessibility bias, an alphabetical list of all participants' forenames and surnames were provided. Nominations between peers were coded 1, with non-nominations coded 0, and non-nominations due to non-responses coded as NA. Nomination data were specified as directed adjacency matrices for all four timewaves capturing advice and contained all advice nominations within the sample. See Table 6 for descriptive statistics.

Analytical Strategy. Analyses were conducted using stochastic actor-oriented models for the coevolution of networks and behaviors (SAOMs: Burk, Steglich & Snijders 2007; Snijders, Steglich & Schweinberger 2017) using RSiena software (Ripley, Snijders, Boda, Voros, & Preciado, 2016). SAOMs are suitable for assessing our hypotheses, as they examine the effects of a specific *dynamic attribute*, in this case prestige and dominance, on network dynamics and also the concurrent effects of the network dynamics on the dynamic attribute.

To do this, SAOMs estimate latent, temporal changes in both network relationships and dynamic attributes as time-aggregated outcomes a series of individual decisions (Steglich, Snijders & Pearson 2010). SAOMs use the initial observed networks and attributes as the starting point of estimation. From this, SAOMs simulate the latent continuous-time changes using a rate function, whereby the overall observed changes between measurement points are decomposed into the smallest possible opportunity for change. This opportunity for change is called a microstep and, during this, an actor is randomly selected and provided the opportunity to create, maintain or dissolve a single tie within their network (Snijders et al. 2010).

To assess the processes that are driving change over time, SAOMs use an objective function. During a microstep, where an actor is presented an opportunity to make a single change in both network ties and dynamic attribute, the actor evaluates their possible choices and weights their decision on the composition and structure of the network and the expression of theoretically-relevant attributes and individual differences of the actors that comprise the network. When evaluating their opportunity for change, actors aim for higher values in the objective function, assessing all possible choices that they can make and ultimately making an optimal change, with a small amount of randomness, which maximises their objective function (Snijders, 2001, 2009). Positive estimated parameter values that comprise the objective function indicate that the process assessed would increase the likelihood of creating or maintaining a tie, or increasing the value of the dynamic attribute, whereas a negative estimate would suggest a tendency away from creating ties or reducing the value of the dynamic attribute. For a general introduction on SAOMs refer to Snijders et al. (2010).

Model specification. Data from the two cohorts assessed were combined and analysed as one large network by specifying structural zeros between classrooms to indicate that relationships between the two cohorts could not exist (Ripley et al. 2018). There were no substantial differences in parameter estimation between the two cohorts. Alongside the effects directly relating to our hypotheses, we specified several structural and theoretically-relevant covariate effects within the current models. To control for the structural interdependencies of the data and to assess the structural processes that govern the development of friendship and advice networks, we specified five elementary structural effects. These effects account for the general

tendency for actors to become more selective when nominating friends and advisors over time (*outdegree*), the tendency for actors to reciprocate nominations over time (*reciprocity*), the tendency for actors to form transitive groups (i.e. if *i* is friends with *j* and *j* is friends with *h*, then *i* is more likely to become friends with *h* over time: *Geometrically weighted edgewise shared partners*), and two effects that assess the tendencies for degree-differentiation (*indegree popularity* and *outdegree activity*). We controlled for the tendency for actors to make friends with, or ask advice from, peers within their task groups (*same task group*) and the tendency towards gender homophily (*same gender*).

To examine the effects related to our hypotheses on the impact of dominance on friendship and advice network dynamics, we specified effects that captured the effect of dominance on indegree nominations (*dominance receiver*), outdegree nominations (*dominance sender*) and the tendency for dominant individuals to selectively assort with friends expressing a similar level of dominance (*dominance similarity*). In relation to our hypotheses the impact of prestige on friendship and advice network dynamics, we specified effects that captured the effect of prestige on indegree nominations (*prestige receiver*), outdegree nominations (*prestige sender*) and the tendency for prestige individuals to selectively assort with friends expressing a similar level of prestige (*prestige similarity*). We included concurrent indegree effect of friendship dynamics on prestige and dominance dynamics (*indegree*) and an effect that captured an influence effect (*average alter*), which captures the tendency for actors to increase or decrease their expression of prestige and dominance based on the average levels of prestige or dominance expressed among their friends. However, an outdegree did not meet the criteria for inclusion based on score-type tests (Ripley et al., 2018). This indicated that an individual's outdegree effect for both friendship

and advice had relationships that encompassed zero and, thus, were not included in the models.

To test our hypotheses relating to the multiplexity of friendship and advice, our final model included cross-network effects of friendship and advice. Dyadic-level effects, which include the main effect of friendship on forming advice ties (*direct association*: and visa-versa) and the tendency to reciprocate advice ties with friendship ties (*reciprocal friendship*: and visa-versa) met the criteria for inclusion in the score-type tests. Two individual-level effects met the inclusion criteria and were specified in the final model. These were the tendency friendship indegree to impact advice indegree popularity (*friendship indegree popularity interaction*), and for friendship outdegree to impact advice outdegree activity (*friendship outdegree activity interaction*).

Model-building procedure. In line with the recommended specification of SAOMs (Burk, Steglich & Snijders, 2007; See also Ripley et al. 2018), both the friendship and advice models were built using a step-wise procedure that prevents model over-specification. In the initial step, a base model was specified that allowed the elementary structural effects to be freely estimated, whilst the theoretically relevant covariate parameters were fixed to zero and their contribution to the objective function was assessed through score-type tests. If the score-type tests indicate that the parameter's effect is significantly different from zero, and thus the parameter does have a unique impact on the model, then it was selected for inclusion in the final, full model. Therefore, all parameters that achieved $\alpha < .05$ in the score-type test and theoretically relevant control variables were included in the full final models to ensure that their unique contributions to the model were partialed out. We

present three models: two uniplex network models that assess friendship and advice in isolation (see Table 8) and a multiplex model that evaluates friendship and advice in unison. The final models yielded good convergence, with overall maximum convergence t-ratios <.25 and individual parameter t-ratios <.10 (as outlined in Ripley et al., 2018). We controlled for time-heterogeneity of effects (Lospinoso, Schweinberger, Snijders, & Ripley, 2011) and the models indicated adequate goodness-of-fit (Ripley et al., 2018; Schweinberger, 2012). Unless otherwise stated, the results reported in following section are from our full final multiplex network-behavioural co-evolution model. (see Table 9).

4.3. Results

Means, standard deviations and Spearman's rank correlations between prestige and dominance can be found in Table 7 which indicates that prestige was significantly related to prestige, and dominance with dominance, at all time waves and that prestige and dominance had no significant, or a weak negative correlation, throughout the study. Moreover, as shown in Table 7, items capturing prestige and dominance had excellent internal consistency at all timewaves (α's >.81).

As shown in Tables 2 and 3, descriptive statistics for the friendship and advice networks indicate that the current networks were in line with data requirements for longitudinal social network analysis (Snijders, Steglich & Van de Bunk, 2010; Veenstra & Steglich, 2012). Individuals, on average, nominated 1.97 friends and 1.52 advisors throughout the study, and there was adequate levels of stable friendship and advice ties between time waves, exhibiting between 32% and 53.3% stable ties (as shown by the Jaccard index in Tables 2 and 3). Throughout the study there was a

relatively low percentage of missing data, all timewaves below 7%, which RSiena handles by using the last observation carried forward technique (Huisman & Steglich, 2008).

4.3.1. Friendship network dynamics

Effects of dominance on friendship network dynamics. The negative dominance receiver parameter in the uniplex friendship model (shown in Table 8) indicates that the individuals higher in perceived dominance were marginally less likely to be nominated as friends over time (θ = -0.042, SE = 0.023, p = 0.059), providing evidence in support of our hypothesis (H1a). However, this effect became more marginal in the full multiplex model (θ = -0.045, SE = 0.026, p = 0.093) Interestingly, in relation to hypothesis 2a, the current results suggest that there was a significant tendency for those high in dominance to nominate friends (θ = 0.081, SE = 0.030, p = 0.007). There was a positive, significant similarity effect for dominance for friendship selection (θ = 1.063, SE = 0.472, p = 0.025), indicating that individuals tended to nominate friends who were perceived as expressing a similar level of dominance to themselves.

Effects of prestige on friendship network dynamics. Prestige had no significant impact on incoming friendship nominations (θ = 0.002, SE = 0.023, p > 0.10) or outgoing friendship nominations (θ =0.039, SE = 0.029, p > 0.10). Nor was there a significant tendency for individuals to select friends who exhibited a similar level of perceived prestige as themselves (θ = 0.265, SE = 0.328, p > 0.10).

Effects of friendship on dominance dynamics. The positive, significant rate parameters within the current model indicate that there was a substantial amount of change in and individual's perceived dominance between observed timewaves (see Table 5). The linear and quadratic shape effects capture the basic trajectory of dominance over time, suggesting that there was some linear change in dominance over time (see Table 5). Results provide evidence in support of our prediction that having higher indegree friendship nominates will reduce an individual's perceived dominance (H5a: θ = -0.026, *SE* = 0.011, p = 0.022). The positive average alter effect for dominance (H4a: θ = 0.012 *SE* = 0.005, p = 0.017), indicates that the average level of an individual's friend's perceived dominance increased their perceived dominance.

Effects of friendship on prestige dynamics. As shown in Table 5, there was a significant rate of change in prestige between observed time waves and the shape parameters indicate that there was some non-linear change in prestige over time. In our uniplex models (See Table 5) results align with our predictions (H5b), higher incoming friendship ties significantly increased an individual's perceived prestige (θ = 0.028, *SE* = 0.012, p = 0.016). Our uniplex models also support our hypothesis that prestige may spread through friendship (expressive) network ties (H6b) and indicate that the average levels of perceived prestige expressed by their friends significantly increases their prestige over time (θ = 0.040, *SE* = 0.010, p = 0.036). However, the effect diminished when assessing the influence effects of both networks on prestige and was not included in the multiplex model.

Cross-network (multiplex) effects of advice on friendship network dynamics. Advice nominations had a strong direct effect on friendship nominations (θ = 3.522, *SE* = 0.452, p < 0.001), indicating that if individuals nominated someone as an

advisor, then they were likely to nominate them as a friend over time. Individuals further tended to reciprocate friendship nominations with advice nominations (θ = 1.500, SE = 0.435, p < 0.001).

Within-network effects on friendship network dynamics. The positive, significant rate parameters shown in Table 5 show that there was a significant amount of change in friendship between observed timewaves. The outdegree (density) parameter captures the general tendency to create and maintain ties. The negative parameter estimate (θ = -5.300 SE = 0.326, p < 0.001) indicates that individuals were likely to be selective in their nominations. Individuals had a strong tendency to reciprocate the friendship nominations that they receiver (θ = 0.874, SE = 0.303, p = 0.004) and tended to form transitive groups, such that friends of friends were nominated as friends (θ = 1.251, SE = 0.181, p < 0.001). There was no significant tendency for an individual's indegree to predict their future indegree (θ = -0.159, SE = 0.132, p >0.10), but individuals who nominated many friends were likely to nominate additional friends over time (θ = 0.736, SE = 0.072, p < 0.001).

Covariate effects on friendship network dynamics. Our uniplex results indicate that there was a tendency towards gender homophily in friendship selection (θ = 0.178, SE = 0.086, p = 0.019), indicating that males tended to nominate males, whilst females were more likely to nominate females. However, this became non-significant in our multiplex model ((θ = 0.013, SE = 0.097, p >0.10). The same team parameter controlled for a multi-level aspect of the current design and accounted for the tendency for individuals to nominate friends within the task groups that they worked. Results indicate that there was a substantial tendency for individuals to nominate task group members as friends (θ = 0.961, SE = 0.180, p < 0.001).

4.3.2. Advice network dynamics

Effects of dominance on advice network dynamics. As expected, results indicate that dominance did not have any substantial impact on incoming advice ties (H7a: θ = -0.013, *SE* = 0.028, $p > 0.10$), nor on asking for advice (H8a: θ = 0.024, *SE* = 0.026, $p > 0.10$). There was a tendency for individuals to ask for advice from others who expressed a dissimilar level of perceived dominance to themselves (H9a: θ = -1.229, *SE* = 0.478, $p = 0.011$).

Effects of prestige on advice network dynamics. In line with our predictions, those high in prestige were nominated more as advisors (H7b: θ = 0.100, *SE* = 0.033, $p = 0.002$) and those high in prestige were less likely to ask others for advice (H8b: θ = -0.107, *SE* =0.033, $p < 0.001$). Results further indicate that individuals did not display a significant tendency to selectively nominate advisors who exhibit a similar level of perceived prestige as themselves (H9b: θ = 0.246, *SE* =0.474, $p > 0.10$).

Effects of advice on dominance dynamics. In the uniplex advice model (shown in Table 5), an individual's dominance decreased alongside the amount of indegree advice ties that they receive (θ = -0.034, *SE* =0.016, $p = 0.035$), which supported our hypotheses (H11a). Interestingly, results suggest that the perceived levels of dominance of an individual's advisors increases that individual's perceived dominance (H10a: θ = 0.049, *SE* =0.018, $p = 0.007$). However, the effect diminished

when assessing the influence effects of both networks on dominance and was not included in the multiplex model.

Effects of advice on prestige dynamics. Incoming advice ties increased an individual's perceived prestige (H11b: $\theta = 0.071$, $SE = 0.019$, $p < 0.001$). Results further support our hypotheses (H10b), indicating that the average level of an individual's advisor's perceived prestige significantly increased the individual's prestige over time ($\theta = 0.075$, $SE = 0.026$, $p = 0.004$).

Cross-network effects of friendship on advice network dynamics. Results demonstrate that there was a direct effect of friendship nominations with advice nominations ($\theta = 3.804$, $SE = 0.336$, $p < 0.001$), such that individuals were more likely to nominate their friends as advisors over time. Individuals tended to reciprocate advice ties with friendship ties ($\theta = 1.919$, $SE = 0.307$, $p < 0.001$). The positive significant mixed indegree popularity parameter ($\theta = 0.841$, $SE = 0.359$, $p = 0.02$) indicates that individuals who are nominated as a friend by many peers are also more likely to be nominated by others as an advisor. The negative significant mixed outdegree activity parameter ($\theta = -0.692$, $SE = 0.183$, $p < 0.001$) suggests that those who nominate many friends were less likely to nominate many advisors.

Within-network effects on advice network dynamics. As shown in Table 5, there was a significant rate of change in advice ties between observed periods and the negative outdegree parameter indicates that individuals were selective about whom they asked advice from ($\theta = -5.444$, $SE = 0.685$, $p < 0.001$). In our uniplex models, individuals tended to reciprocate the advice nominations that they received ($\theta = 1.899$, $SE = 0.166$, $p < 0.001$). However, this effect was non-significant in our

multiplex models (θ = -0.496, SE = 0.32, p >0.10). Individuals tended to form transitive groups (θ = 1.468, SE = 0.491, p = 0.003), such that individuals were likely ask the advisor of their advisor for advice. The was a significant negative effect of an individual's previous advice indegree on their future incoming advice nominations (θ = -1.100, SE = 0.421, p = 0.009). However, there was a significant tendency for individuals who have high outgoing advice nominations to nominate more advisors over time (θ = 1.004, SE = 0.115, p < 0.001).

Covariate effects on advice network dynamics. Uniplex results suggest that there was no significant tendency for individuals to ask work-related advice from others of the same gender (θ = 0.138, SE = 0.089, p > 0.10). However, multiplex results indicate that there was a significant tendency for individuals to ask advice from others of the same gender (θ = 0.233, SE = 0.102, p = 0.026). There was a strong tendency for individuals to ask those within their respective task groups for advice (θ = 1.585, SE = 0.151, p < 0.001).

4. Discussion

As summarised in Table 1, we find empirical support for most predictions derived from our hypotheses. Individuals tended not to nominate those high in dominance as friends over time and that, when individuals nominated friends, they selectively chose those who expressed a similar level of dominance to themselves. Dominance was not related to advice and had no impact on choosing or being chosen as advisors. Moreover, an individual's perceived dominance reduced when others nominated them as friends or advisors, and there were peer influences on an individual's perceived dominance, with friends' and advisors' dominance positively

impacting an individual's dominance. In relation to prestige, the present findings confirm the majority of our predictions and indicate that prestige has a strong bidirectional relationship with instrumental support. Those high in prestige were sought more as advisors and were less likely to ask for advice. Similarity in prestige had no impact on the initial selection of either friends or advisors but found that the prestige of an individual's friends and advisors increased their prestige over time. Our results further demonstrate that receiving friendship ties and being asked for advice increased an individual's prestige over time. Furthermore, the present findings shed light on the multiplex nature of instrumental and expressive ties, highlighting that advice ties and friendship ties have direct effects upon one another.

While the existing body of literature has identified the relationships that prestige and dominance have with preferences for instrumental relationships, often operationalized as advice or food sharing (Hawkes & Bliege-Bird, 2001; Henrich & Broesch, 2011; Torló & Lomi, 2017; Weissner, 2005) and expressive relationships, frequently measured as preference for social partners or friends (Barclay, 2013; Torló & Lomi, 2017; Willer, 2009), the extant literature has theorised that these relationships to flow in a single 'causal' direction and evidence has been derived from experimental or cross-sectional observations, limiting the opportunity to observe bidirectional effects. The current research synthesises these literatures, outlining that social hierarchy is inherently relational and operates within complex, dynamic social networks. We further proposed that networks of expressive and instrumental ties, which are two interconnected facets of human cooperation that have coevolved, both guide and are guided by the trajectories of prestige and dominance across many contexts. By taking this approach, the present research makes an important contribution to literatures assessing both cooperation and social hierarchy.

4.4.1. Implications for the dual model of social hierarchy

The dual model of social hierarchy proposes that humans attain social rank through dominance, by harbouring traits that provoke fear among others, and prestige, founded upon skill, knowledge and prosociality (Cheng & Tracy, 2014; Henrich & Gil-White, 2001). The current research extends this model by demonstrating that these dynamics are intrinsically related to human social networks. Taken together, the present findings emphasise the distinction between prestige and dominance, highlight the divergent associations that prestige and dominance have with social networks and lend support to a growing body of empirical literature that highlights the prestige-dominance distinction (Cheng et al., 2010, 2013; Garfield & Hagan, under review; Redhead, 2016; von Rueden et al., 2008). The finding that prestige has a strong impact on the selection of instrumental ties, with those high in prestige having high indegrees, while dominance had no association, suggests that prestige and dominance have distinct implications for relationships that individuals foster. These findings, in combination with our findings that receiving advice nominations in fact decreases an individual's perceived dominance, further imply that dominance does not impact and is not contingent on networks of cooperative relationships. In contrast to this, our results suggest that prestige has an important, bidirectional relationship with these networks of cooperation, and both fosters cooperation in groups and is propagated by such cooperation.

The present findings highlight the connection that prestige has with instrumental support and lend empirical support for the association that prestige may

have with cultural learning (Henrich & Gil-White, 2001). Individuals ask advice from those high in prestige and, in turn, prestige is transmitted through these ties over time, with the average levels of prestige of an individual's advisors increasing that individual's prestige over time. The association that such instrumental network ties produce over time allows individuals to learn skills and acquire knowledge within their context and, thus, boosts the individual's capacity to not only acquire resources and skill in a valued domain, but also ability to confer benefits to others. However, there will always be a discrepancy between these initially lower-prestige individuals and those higher-prestige advisors in the positions that they occupy within a hierarchy. Our findings suggest that receiving an incoming advice tie increases an individual's prestige, suggesting that these incoming ties signal an individual's ability and willingness to confer benefits. Alongside this such instrumental networks emerge through transitive processes, such that if individual *h* was the advisor of individual *i*, and *j* was the advisor of *h*, then *i* is likely to also ask advice from *j*. As an example, should individual *h*'s prestige increase due to prestige being transmitted through advice ties with those higher in prestige, here individual *j*, then this not only increases the likelihood of *h* gaining advise nominations, but also of their advisor, *j*, receiving further advice nominations.

The present findings shed light on the association that dominance has with positive network ties. However, given the main components of a dominance profile (i.e. aggression, narcissism), those high in dominance are likely to engage in negative affect expressive ties (henceforth referred to as negative ties) with those whom they are proximate with. Negative ties represent a recurring set of negative judgements and behavioural intentions towards another person that amount to relatively destructive

relationships that are characterised by conflict (Labianca & Brass, 2006; Labianca, 2014).

While these ties seem, in most collaborative group settings, to have a deleterious impact on group and individual outcomes (Baldwin, Bedell & johnson, 1997; Labianca, 2013), in other settings an individual high in dominance may wield these negative relational behaviors with success. The current approach posits that dominance may only be efficacious in the social systems where expressive ties are not necessarily based on positive affect and social rank is not principally contingent on providing instrumental support. Rather, when individuals send expressive ties to others in an attempt to lessen the costs that they may be both willing and able to impose. For example, individuals high in dominance-related traits and bullies are popular and high-ranking in developmental hierarchies, with those proximate to them being friends with them as friends are less likely to become victims of bullying (Hawley, 1999; Pellegrini & Long, 2003; Redhead, Cheng & O'Gorman, 2018; Sijstema et al., 2009. Thus, the varying success of such negative ties may be inherently linked with the varying success of dominance between contexts and societies.

4.4.2. Network multiplexity and cooperation

The present findings build upon the notion that human social life is patterned by multiple relationships and provides empirical evidence that demonstrates that these relationships concurrently impact one another. These networks of relations show striking structural similarities in ways that they emerge and may solve a number of issues relating to coordination and cooperation that may have been encountered

during human evolution (Apicella et al., 2012; Boyd & Richerson, 1988; Nowak, M., 2005; Von Rueden & Van Vugt, 2015). The current research builds upon this literature, hypothesising and finding that equivalent acts of cooperation, that is instrumental network ties (operationalized as advice), both facilitate and are expedited by expressive network ties that promote positive affect (operationalized as friendship). We further demonstrate that individuals have a strong tendency to reciprocate expressive ties with instrumental ties and visa-versa, and that these networks are relatively distinct domains, having limited individual-level associations (i.e. interactions between degree), except the positive impact that in-degrees of expressive ties have with in-degree popularity in instrumental ties.

Given the bi-directional association that these cooperative ties have with one another, the present research establishes that instrumental and expressive network ties are two interlocking components of human cooperation. Instrumental networks are different forms of cooperative behaviours, which are important in human groups as we often exhibit high levels of interdependence for subsistence (Winterhalder, 1986). Expressive ties facilitate these cooperative acts of instrumental support, especially when the interests of individuals may diverge. Our results indicate that individuals are more likely to give advice to friends, which is in-keeping with theory relating to the evolution of cooperation (Majolo et al., 2006; Tooby & Cosmides, 1996; Trivers, 1971). Importantly, the present findings revealed that, when assessing the emergence of expressive and instrumental ties in union, individuals were not likely to directly reciprocate instrumental ties with instrumental ties, which seems plausible given the simultaneous association that prestige has with expressive ties. Rather, individuals in the current sample indirectly reciprocated these instrumental ties with expressive ties,

which emphasises both the importance of the multiplexity of these networks and also of prestige for the stable and enduring cooperation often observed in human groups.

4.4.3. Limitations and future directions

Whilst the current research had a number of significant strengths, there were limitations that should be addressed in future research. One such limitation is that data are derived from North American undergraduate students. Such populations may not be representative of the world's populations and our findings may be constrained to collaborative group behaviours in WEIRD settings. Future research in non-WEIRD settings, and comparative longitudinal cross-cultural examinations of the hypotheses posed would provide more ecologically-valid tests of such relationships and allow for empirical tests of when dominance is successful. In combination with this, the present research—akin to the majority of the extant social network literature—focussed primarily on 'positive' instrumental and expressive ties. Future research should aim to assess the hypothesised association that prestige and dominance have with negative ties across a broad range of ecologies where divergences may emerge as a consequence of potential differences in environmental pressure, rank-related norms or the overall structure of the social networks.

One surprising result was that prestige was not associated with friendship in the current sample. Individuals invest in social relationships to accrue social capital and those high in social rank may focus their attention on different types of social relationships in different contexts. In the current context individuals within the classrooms were all working in groups to complete a task and, therefore, their goals

aligned. In contexts where the interests of group members converge, high-ranking group members are often task-oriented and associated with instrumental support ties and expressive ties are less important for facilitating cooperation and team effectiveness (Thye, 2000; Yukl, 2008; Van Vugt, Hogan & Kaiser, 2008). Moreover, individuals in the current sample may have friendships outside of the classrooms—be they physical or online friendships. Thus, the present network boundary and context is limited to assessing friendships that occur within the classrooms and may not capture important, emotionally close friendships that may occur outside of the boundary, limit the efficacy and motivation to forge friendships with others, and in turn dampen the relationship that it has with prestige. Future research assessing contexts where expressive ties are of paramount importance for facilitating instrumental ties, such as when the interests of group members substantially diverge (Thye, 2000; Yukl, 2006; Van Vugt, Hogan & Kaiser, 2008), and track expressive ties over a longer period of time, will provide much need insight to the bidirectional relationships that expressive ties have with both prestige and dominance.

4.4.4. Conclusions

The present findings make several theoretical and methodological contributions to the existing literature, emphasising not only the importance of time, but also the concurrent weighting that social relationships have on processes related to social hierarchy. Overall, the current research highlights that processes of social hierarchy and cooperation are dynamic, interlocking components of human sociality and have distinct bidirectional relationships with prestige and dominance.

Table 4.
Outline of dynamic network processes, their predicted relationships with dominance and prestige, a brief explanation for the prediction and the effect observed in the current research.

Dynamic network process	Predicted effect			Effect found		
	a. Dominance	b. Prestige	Multiplexity	a. Dominance	b. Prestige	Multiplexity
Friendship (Expressive network ties)						
1. High incoming friendship nominations	Negative	Positive	-	Negative/Null	Null	-
2. High outgoing friendship nominations	Negative	Positive	-	Positive	Null	-
3. Similarity based on initial selection of friends (network selection)	Positive	Null	-	**Positive**	**Null**	-
4. Similarity based on network influence from friendship	Positive	Positive	-	**Positive**	**Positive/Null**	-
5. Incoming friendship ties increase perceptions of the profile	Negative	Positive	-	**Negative**	**Positive/Null**	-
6. Outgoing friendship ties increase perceptions of the profile	Null	Null	-	**Null**	**Null**	-
Advice (Instrumental network ties)						
7. High incoming advice nominations	Negative /Null	Positive	-	**Null**	**Positive**	-
8. High outgoing advice nominations	Negative	Negative	-	**Null**	**Negative**	-
9. Similarity based on initial selection of similar advisors (network selection)	Null	Null	-	**Null**	**Null**	-
10. Similarity based on network influence from advice	Null	Positive	-	Positive/Null	**Positive**	-

11. Incoming advice ties increase perceptions of the profile	Negative	Positive	-	**Negative**	**Positive**	-
12. Outgoing advice ties increase perceptions of the profile	Null	Negative	-	**Null**	Null	-
Cross-network (multiplex) processes						
13. Expressive ties will lead to the formation of instrumental ties.	-	-	Positive	-	-	**Positive**
14. Instrumental ties will lead to the formation of expressive ties.	-	-	Positive	-	-	**Positive**
15. Individuals will reciprocate expressive ties with instrumental ties.	-	-	Positive	-	-	**Positive**
16. Individuals will reciprocate instrumental ties with expressive ties.	-	-	Positive	-	-	**Positive**

Note. The effects found that support our hypotheses are in **bold.**

Table 5.
Descriptive statistics friendship networks.

	Friendship Network			
	TW1	TW2	TW3	TW4
Density[a]	0.008	0.009	0.008	0.009
Average degree	1.89	2.08	1.87	2.04
Number of ties	436	475	423	450
Asymmetrical dyads	434	382	512	344
Mutual dyads	196	268	146	246
Missing data	2.4%	3.3%	4.6%	6.3%
Tie changes				
Creating ties (0 □ 1)	155	111	186	
Dissolving ties (1 □ 0)	115	160	146	
Stable ties (1 □ 1)	302	209	256	
Jaccard index [b]	52.8%	53.3%	43.5%	

Note. $N = 236$ x $T = 4$. [a] Density was calculated as N of ties divided by the total number of ties. [b] Jaccard index represents the fraction of stable ties relative to created ties, dissolved ties and stable ties.

Table 6.
Descriptive statistics for advice networks.

	Advice Network			
	TW1	TW2	TW3	TW4
Density[a]	0.006	0.007	0.007	0.006
Average degree	1.402	1.569	1.736	1.348
Number of ties	323	358	391	298
Asymmetrical dyads	392	380	436	354
Mutual dyads	114	156	150	94
Missing data	2.4%	3.3%	4.6%	6.3%
Tie changes				
Creating ties (0 □ 1)	187	165	84	
Dissolving ties (1 □ 0)	153	123	146	
Stable ties (1 □ 1)	160	146	199	
Jaccard index [b]	32%	44%	46.4%	

Note. $N = 236$ x $T = 4$. [a] Density was calculated as N of ties divided by the total number of ties. [b] Jaccard index represents the fraction of stable ties relative to created ties, dissolved ties and stable ties.

Table 7.
Descriptive statistics for and Spearman's rank correlations between prestige and dominance.

	Mean (SD)	Missing data	1	2	3	4	5	6	7	8
1. Prestige T_1	5.48 (2.86)	5%	[a] .88	-	-	-	-	-	-	-
2. Prestige T_2	5.55 (2.82)	3%	.369***	[a] .89	-	-	-	-	-	-
3. Prestige T_3	5.52 (2.83)	3%	.318***	.677***	[a] .88	-	-	-	-	-
4. Prestige T_4	5.46 (2.80)	3%	.249***	.611***	.765***	[a] .90	-	-	-	-
5. Dominance T_1	5.47 (2.84)	5%	-.063	-.097	-.173**	-.152*	[a] .82	-	-	-
6. Dominance T_2	5.57 (2.76)	3%	-.065	-.054	-.063	-.034	.518***	[a] .86	-	-
7. Dominance T_3	5.49 (2.88)	3%	-.037	.016	-.088	-.079	.479***	.565***	[a] .91	-
8. Dominance T_4	5.59 (2.78)	3%	-.103	.026	-.084	-.129[†]	.421***	.531***	.613***	[a] .93

Note.
[a] Cronbach's Alpha (α) reliabilities.
[†] $p < 0.10$ * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$ (two-tailed tests).

Table 8.
Uniplex Network-Behavioural Dynamics of Friendship, Instrumental Advice, Dominance and Prestige.

	Friendship Dynamics	Advice Dynamics

Parameter	Estimate (θ)	Standard Error	Odds Ratio *(OR)*	*p*-value	Estimate (θ)	Standard Error	Odds Ratio *(OR)*	*p*-value
Network Dynamics								
Rate t^1-t^2	2.268***	0.186	NA	<0.001	4.669***	0.488	NA	<0.001
Rate t^2-t^3	2.206***	0.198	NA	<0.001	3.009***	0.302	NA	<0.001
Rate t^3-t^4	3.377***	0.282	NA	<0.001	2.357***	0.246	NA	<0.001
Outdegree (Density)	-4.948***	0.266	0.007	<0.001	-5.607***	0.312	0.004	<0.001
Reciprocity	2.173***	0.142	8.785	<0.001	1.899***	0.166	6.679	<0.001
Transitive Group Formation (GWESP)	2.158***	0.314	8.654	<0.001	0.686***	0.210	1.986	0.001
Indegree Popularity (sqrt)	-0.011	0.116	0.989	>.10	0.050	0.139	1.051	>.10
Outdegree Activity (sqrt)	0.655***	0.062	1.925	<0.001	0.832***	0.074	2.298	<0.001
Same Gender	0.178*	0.086	1.195	0.019	0.138	0.089	1.093	>.10
Same Team	1.849***	0.135	6.354	<0.001	2.450***	0.141	11.588	<0.001
Dominance Receiver	-0.042*	0.023	0.959	0.059	-0.015	0.022	0.985	>.10
Dominance Sender	0.054*	0.023	1.056	0.018	0.002	0.031	1.002	>.10
Dominance Similarity	0.769*	0.363	2.158	0.035	-0.432	0.358	0.649	>.10
Prestige Receiver	0.018	0.021	1.018	>.10	0.087***	0.027	1.091	0.001
Prestige Sender	0.025	0.023	1.025	>.10	-0.120***	0.031	0.887	<0.001
Prestige Similarity	0.348	0.307	1.416	>.10	0.440	0.383	1.553	>.10
Dominance Dynamics								
Rate t^1-t^2	18.512***	2.524	NA	<0.001	17.737***	2.377	NA	<0.001
Rate t^2-t^3	14.446***	2.475	NA	<0.001	14.178***	1.931	NA	<0.001
Rate t^3-t^4	12.419***	2.124	NA	<0.001	12.071***	1.629	NA	<0.001
Linear Shape	0.066*	0.029	NA	0.022	0.072*	0.028	NA	0.011
Quadratic Shape	0.002	0.004	NA	>.10	0.003	0.004	NA	>.10

Indegree Effect	-0.026*	0.011	0.974	0.022	-0.034*	0.016	0.967	0.035
Average Alter	0.029†	0.017	1.029	0.093	0.049**	0.018	1.050	0.007
Prestige Dynamics								
Rate t^1-t^2	27.866***	3.827	NA	<0.001	26.327***	3.939	NA	<0.001
Rate t^2-t^3	9.375***	1.172	NA	<0.001	9.167***	1.459	NA	<0.001
Rate t^3-t^4	5.542***	0.731	NA	<0.001	5.496***	0.745	NA	<0.001
Linear Shape	-0.064*	0.029	NA	0.028	-0.117***	0.036	NA	0.001
Quadratic Shape	0.002	0.004	NA	>.10	0.004	0.006	NA	>.10
Indegree Effect	0.028*	0.012	1.028	0.016	0.071***	0.019	1.074	<0.001
Average Alter	0.040*	0.019	1.041	0.036	0.075**	0.026	1.078	0.004

Note.
$N = 236$ X $T = 4$. Significance tests were performed by dividing the estimates by their standard error to produce a t-value that is normally distributed under the null hypothesis. Maximum convergence t-ratio < 0.25 and parameter t-ratios < 0.10.
† $p < 0.10$ * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$ (two-tailed tests).

Table 9.
Multiplex Network-Behavioural Dynamics of Friendship, Instrumental Advice, Dominance and Prestige.

	Friendship Dynamics				Advice Dynamics			
Parameter	Estimate (θ)	Standard Error	Odds Ratio *(OR)*	*p*-value	Estimate (θ)	Standard Error	Odds Ratio *(OR)*	*p*-value
<u>Network Dynamics</u>								
Rate t^1-t^2	2.628***	0.235	NA	<0.001	7.906***	0.962	NA	<0.001
Rate t^2-t^3	2.340***	0.192	NA	<0.001	3.968***	0.410	NA	<0.001
Rate t^3-t^4	3.950***	0.326	NA	<0.001	2.861***	0.296	NA	<0.001
Outdegree (Density)	-5.300***	0.326	0.005	<0.001	-5.444***	0.685	0.004	<0.001
Reciprocity	0.874**	0.303	2.397	0.004	-0.496	0.320	0.609	>.10
Transitive Group Formation (GWESP)	1.251***	0.181	3.494	<0.001	1.468 ***	0.491	4.341	0.001
Indegree Popularity (sqrt)	-0.159	0.132	0.853	>.10	-1.100**	0.421	0.333	0.009
Outdegree Activity (sqrt)	0.736***	0.076	2.088	<0.001	1.004***	0.115	2.729	<0.001
Same Gender	0.013	0.097	1.013	>.10	0.233*	0.102	1.262	0.026
Same Team	0.961***	0.180	2.614	<0.001	1.585***	0.151	4.879	<0.001
Dominance Receiver	-0.045†	0.027	0.956	0.093	-0.013	0.028	0.987	>.10
Dominance Sender	0.081**	0.030	1.084	0.007	0.024	0.026	1.024	>.10
Dominance Similarity	1.063*	0.472	2.895	0.025	-1.229*	0.478	0.293	0.011
Prestige Receiver	0.002	0.023	1.002	>.10	0.100**	0.032	1.105	0.002
Prestige Sender	0.039	0.029	1.477	>.10	-0.107***	0.033	0.899	0.001
Prestige Similarity	0.265	0.328	1.288	>.10	0.246	0.474	1.279	>.10
<u>Cross-Network Effects</u>								
Advice: Direct Association	3.522***	0.452	33.852	<.001				

Reciprocal Advice	1.500***	0.435	4.482	<.001				
Friendship: Direct Association	-	-	-	-	3.804***	0.336	44.880	<.001
Reciprocal Friendship	-	-	-	-	1.919***	0.307	6.814	<.001
Friendship: In-Degree Popularity (Sqrt)	-	-	-	-	0.841*	0.359	2.319	0.02
Friendship: Out-Degree Activity (Sqrt)	-	-	-	-	-0.692***	0.183	0.501	<.001
<u>Dominance Dynamics</u>								
Rate t^1-t^2	18.261***	2.349	NA	<0.001	-	-	-	-
Rate t^2-t^3	14.636***	1.743	NA	<0.001	-	-	-	-
Rate t^3-t^4	12.326***	1.859	NA	<0.001	-	-	-	-
Linear Shape	0.065*	0.026	NA	0.013	-	-	-	-
Quadratic Shape	0.003	0.004	NA	>.10	-	-	-	-
Indegree Effect	-0.026*	0.011	0.974	0.022	-	-	-	-
Average Alter	0.012*	0.005	1.012	0.017	-	-	-	-
<u>Prestige Dynamics</u>								
Rate t^1-t^2	-	-	-	-	25.73***	3.376	NA	<0.001
Rate t^2-t^3	-	-	-	-	9.416***	1.469	NA	<0.001
Rate t^3-t^4	-	-	-	-	5.632***	0.681	NA	<0.001
Linear Shape	-	-	-	-	-0.103***	0.033	NA	0.001
Quadratic Shape	-	-	-	-	-0.002	0.005	NA	>.10
Indegree Effect	-	-	-	-	0.053***	0.017	1.054	<0.001
Average Alter	-	-	-	-	0.028***	0.009	1.028	<0.001

Note.
N = 236 X T = 4. Significance tests were performed by dividing the estimates by their standard error to produce a t-value that is normally

distributed under the null hypothesis. Maximum convergence t-ratio < 0.25 and parameter t-ratios < 0.10.
† $p < 0.10$ * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$ (two-tailed tests).

5

The dynamics of cooperation and status in a small-scale society

5.1. Introduction

Cooperation is often motivated by opportunities to enhance social status. Schools lure philanthropists with naming rights to buildings. Donors to charities tend to give according to publicized contribution category thresholds (Harbaugh 1998). In general, people contribute more to public goods when their identity and the amount they give are made visible to others (Rege & Telle 2004; Hardy and van Vugt 2006; Bereckzei et al. 2007).

By acquiring reputations for greater ability and willingness to confer benefits (i.e. prestige), individuals are granted greater access to contested material and social resources (i.e. status). Several evolutionary models describe these links, including costly signalling (Bliege Bird, Smith, and Bird 2001; Gintis, Smith and Bowles 2001), reputation-based partner choice (Roberts 1998; Barclay and Willer 2007), and service-for-prestige (Willer 2009; Price and van Vugt 2014). According to these models, generously sharing valued and difficult-to-acquire resources, labour, or information results in group-wide favouritism in subsequent exchange, advantageous alliances, political influence, or mating opportunity.

However, cooperation is as likely to be a consequence as to be a cause of status differences, for at least four reasons. First, greater access to contested resources enhances individuals' ability to build prestige and increase their social following via cooperation. Status is self-reinforcing (Merton 1968). Second, status may motivate continued generosity, in order to signal that one's status is justified or one's leadership is trustworthy (Blau 1964). Such generosity on the part of high status individuals may become normative, i.e. "noblesse oblige". Third, cooperation on the part of high status individuals may motivate cooperation by other group members, due to

prestige-biased imitation (Henrich et al. 2015). Fourth, by forming cooperative partnerships with high status individuals, group members elevate their own status by gaining access to high status individuals' information (Henrich and Gil-White 2001), resources, or coalitions.

Unifying these models is the hypothesis that a group's cooperation network and its distribution of (prestige-based) status have an inherently dynamic relationship. Cooperation and status hierarchy have coevolved in human groups. Despite much research on cooperation and status, there are no tests of this hypothesis in small-scale societies. Experiments demonstrate positive effects of cooperation on status differences (Milinski et al. 2002; Harrell 2018) and status differences on cooperation (Eckel et al. 2010; Baldassari and Grossman 2013; Fiddick et al. 2013), but few test for a dynamic relationships (but see Willer 2009). Doing so can parse the unique, bidirectional effects that status and cooperation have on one another. Field studies in traditional societies find that individuals who receive more social support or wield more political influence are skilled and generous food producers (Gurven et al., 2000; Sugiyama and Sugiyama, 2003; Patton 2005; von Rueden et al. 2008; Nolin 2012; Bliege Bird and Power, 2015; Ready and Power, 2018), share valued information (Schniter et al. 2015; Smith et al. 2017), or make costly contributions to collective action (Price 2003; Lyle and Smith 2014; Glowacki and von Rueden 2015; Macfarlan and Lyle 2015). However, extant field studies are cross-sectional, so they lack tests of dynamics and their interpretation is subject to potential endogeneity or reverse causality problems (See Chapter 3).

In a community of Tsimane forager-horticulturalists in Amazonian Bolivia, we study the dynamics of cooperation and social status over an eight-year period. The Tsimane are relatively

egalitarian, in that there is no coercive leadership and minimal material wealth to contest. Men in the village wield more overt political influence than women, in part due to a division of labour that constrains women's networking beyond the extended household (von Rueden et al. 2018). For this study, we focused our attention on men. We collected three waves of panel data on all men in the village (avg. *n*=80). Wave 1 of the data was collected in 2009, wave 2 in 2014 and wave 3 in 2018. At each wave, men listed other adult men who shared food with them or assisted them in hunting, fishing, logging, or horticultural labour over the previous six months (see Figure 1a). At the same time, a sample of these men photo-ranked all other adult men on two measures of status: influence during village meetings and respect (see Figure 1b). Peer-ratings can be an efficient and accurate method for producing quantitative data from local knowledge (Reyes-Garcia et al. 2016; Stibbard-Hawkes et al. 2018). For example, Werner's study of status among the Mekranoti of Brazil (1981) relies on peer ratings, which correlate strongly with his observational measures.

Using longitudinal social network analysis, we test two predictions: (1) higher status individuals are more likely to gain cooperation partners, and (2) individuals increase their social status by cooperating with higher status individuals. The first prediction reflects a process of network selection (tie formation) while the second prediction reflects a process of network influence (ties affect individuals' attributes: Steglich et al., 2010). Both predictions depart from models of the evolution of cooperation, which rely on network selection but between similar behavioural types (Santos et al. 2006; Lehmann & Keller, 2006; Nowak 2006). Instead, we posit tie formation predominantly between different behavioural types and, in turn, similarity of connected individuals resulting more from network influence than from network selection. Individuals do

not aim to choose partners of similar status to themselves, at least initially. This is because of a market-like competition between higher status individuals, and also between those low in status, with high status individuals aiming to increase or maintain their followership and those low in status seeking high status cooperation partners to boost their own status and also gain access to the resources that high status other possess.

Our analytical approach is stochastic actor-oriented modelling (SAOMs: See Snijders et al. 2010). SAOMs estimate the node-level (individual actor), dyad-level (partner), and network-level (group) mechanisms driving change in network ties and in the attributes of actors. Network-level effects include the density of the network, but we also include dyad-level (i.e. reciprocity) and individual-level (i.e. indegree popularity) structural effects. Our models include several covariates at both the node and dyad levels: age, weight, height, upper body strength, income, and kinship of cooperators. We analyze our two photo-ranked status measures as a single dependent 'behaviour' and our three size and strength measures as a single covariate, according to a maximum likelihood factor analysis. See SI for descriptives of actor covariates and details of the factor analysis. As a reliability check, we compare men's status to a cross-section of self-reported cooperation partners in another community from the same population.

5.2. Methods

5.2.1. Ethnographic Setting

The Tsimane live in small villages in the neotropics of central Bolivia. Their economy is based on swidden horticulture (plantains, manioc, rice, and corn), hunting, fishing, and fruit gathering.

Food sharing and collaboration in productive activities tend to be concentrated within extended families residing in the same or nearby households (Hooper et al., 2015). However, unrelated village members will regularly visit each other to socialize and drink *shocdye'* (chicha), an alcoholic beverage fermented from manioc and maize (Hooper et al., 2013). The sexual division of labour is pronounced. Women average approximately 9 offspring over their lifetime and do the large majority of direct childcare and food processing (McAllister et al., 2012). The Tsimane have no documented history of intervillage warfare. Within villages, conflicts tend to be resolved by the parties directly involved. For many of the conflicts that remain unresolved, third parties within the extended family or in the village may step in to help mediate. Villagers also hold meetings to respond to incursion by illegal loggers or other colonists, negotiate with itinerant merchants, or coordinate projects with the Bolivian government or NGOs. The Tsimane remained largely unconnected to Bolivian society until the mid twentieth century with the arrival of Protestant and Catholic missionaries (Chicchón, 1992). Average income is <$2 (US) per day from sale of horticultural products and sporadic wage labour with loggers and ranchers.

5.2.2. Data Collection

Three waves of panel data, including status rankings and reported cooperation partners, were collected from the entire adult male population (above 21 years old) of one Tsimane village. Data were collected in 2009 (n=72), 2014 (n=78) and 2017 (n=89). Growth in adult male population size is due to immigration, in addition to more boys entering adulthood than adult men dying. A single wave of the panel data was collected in 2008/2009 from all adult men in another Tsimane village (n=73). Fieldwork was approved by the institutional review boards of the University of California, Santa Barbara and the University of Richmond. All study

participants provided informed consent, and methods were approved by the Tsimane government and village leaders.

5.2.3. Cooperation Networks

Networks of cooperation were constructed using a 'name generator' approach, with men freely listing other men within the village who had shared meat with them or assisted them in hunting, fishing, logging, or horticultural labour over the previous 6 months. Networks were sociocentric, binary, and directed. For the longitudinal analysis, the population was restricted to adult men (avg. n=68) who were present within the village in at least two waves of data collection (see Figure 2a-c). The composition change observed in the networks was modelled through the method of joiners and leavers (Huisman & Snijders, 2003). See SI for further description of the networks.

5.2.4. Social Status

To generate status rankings at each wave and in each village, roughly half of the adult men in each village were randomly selected as rankers (Von Rueden et al., 2008, 2010). The rankers represented most ages and all extended families within their village. Each ranker was shown two arrays of 8 photographs, each array a subset of other men from their community. Rankers were asked to rank the men in each array from highest to lowest according to "who is most respected". Photos were Polaroids^{TM} of the top-half of each man's body, set against as neutral a background as possible. Rankers evaluated two additional arrays of photos according to "whose voice carries the most weight during community debates."

The particular photos in each array were selected according to a matrix based on a projective plane. Each number in the matrix corresponded to a photo, and each vector in the matrix corresponded to a particular photo array. By picking photo arrays according to vectors in these matrices, we (1) minimized the number of photos each ranker evaluated, while (2) ensuring comparison of every photo to every other photo and (3) ensuring an equal number of rankings of each man. A maximum likelihood factor analysis indicated that the two photo-ranked status measures comprise a distinct factor that has good internal consistency in each village and at every time wave (with $\alpha > .70$ throughout). Thus, we evaluate status as the average of the two photo-ranked measures. See SI for additional explication of the photo-ranking procedure and factor analysis.

Our confidence in the validity of the photo-ranking is strengthened by ethnographic observation. In the village assessed longitudinally, influence ranking in 2009 predicted who spoke more frequently during community meetings attended by CvR that year ($r = 0.53$, $p < 0.001$, $n = 73$). The same was true for influence ranking and community meetings attended by CvR in 2014 ($r = 0.67$, $p = 0.002$, $n = 49$).

5.2.5. Covariates

All demographic data used to age individuals and determine kinship come from reproductive history interviews first collected from 2003-2005 and updated annually thereafter (Gurven et al. 2007). Individuals were analyzed as kin if they were brothers or father and son (whether consanguineal or in-law). This definition of kinship reflects the concentration of Tsimane social life within clusters of households consisting of siblings, their spouses, their parents, and their

children. At each wave, household income was determined by asking men about all potential sources of income over the past year, including wage labour and sales of forest and horticultural goods. Every 1-3 years, clinicians employed with the Tsimane Health and Life History Project (THLHP: http://www.unm.edu/~tsimane) measured participants' height and weight with a portable stadiometer and a digital weigh scale, respectively. Shoulder and chest strength were measured with a Lafayette Manual Muscle Tester and grip strength was measured with a Smedley III dynamometer. We summed these values to create a composite upper body strength measure. A maximum likelihood factor analysis indicated that height, weight, and upper body strength comprised a distinct factor with adequate internal consistency. Thus, we averaged these size and strength measures to analyze them as a single covariate. See SI for covariate descriptives.

5.2.6. Analytical Strategy

Analyses were conducted using stochastic actor-oriented modelling (SAOMs: See Snijders et al. 2010) using RSiena software (Simulation Investigation for Empirical Network Analysis: RSiena version 1.2-4 in R 3.4.2; Ripley et al., 2018). SAOMs estimate latent changes in a network, and 'behaviours' within that network, between observed time points. These changes are modelled as a continuous-time process, and actors are assumed to control their outgoing ties and the expression of 'behaviours' in a succession of multiple small steps (termed 'microsteps': Snijders et al., 2010). SAOMs estimate the rate of opportunities for change and further estimate the node-level (individual actor), dyad-level, and network-level mechanisms driving change using an evaluation function. A positive parameter estimate would indicate that the parameter produced a preference for creation or maintenance of a tie or an increase in a tie-dependent 'behaviour'.

For the longitudinal network analysis, a network-behaviour co-evolution SAOM was specified. This procedure combines SAOMs for a one-mode network with a dependent 'behaviour' variable (Snijders, Steglich & Schweinberger, 2007) to simultaneously assess the temporal relationship that cooperation network dynamics (the dependent one-mode network) have with status (the dependent 'behaviour'). The model was built using the recommended step-wise procedure. Endogenous network effects, kinship, age, income and physical strength and size were controlled for within the evaluation function. The group mean of the actor covariates is substracted from each actor's score and are stored within the SAOM data objects (Ripley et al. 2018). These centered scores are used for calculations and allow for more comparable estimates between covariates. Further details on model specification and model building procedure can be found in the Supplementary Information. The model had good convergence, with an overall maximum convergence t-ratio of 0.17 and individual parameter t-ratios <0.10, and controlled for any time-heterogeneity of effects (Lospinoso, Schweinberger & Snijders, 2011). For the cross-sectional network analysis, we used an exponential random graph modelling (ERGM). See SI for details.

5.3. Results

5.3.1. Within-Network Effects on Cooperation Dynamics

The results shown in Table 10 present the parameter estimates (θ) that indicate the log-likelihood, the odds ratios and significance of effects. There was a significant rate of change in cooperation ties throughout the observed period, with changes in cooperative ties peaking between period 1 and period 2 ($\theta = 37.168$, $SE = 8.672$, $p < 0.001$), reflecting the greater distance

in time between observations Results suggest that actors had a strong tendency to reciprocate cooperative partnership ties over time ($\theta = 1.55$, $SE = 0.121$, $p < 0.001$). We also find a strong tendency for transitive groups of cooperation partners to form ($\theta = 1.422$, $SE = 0.098$, $p < 0.001$). This indicates that individuals attend to, and are more likely to send ties to, who their cooperative partners are cooperating with, such that if individual *i* nominated individual *h* as a cooperative partner and individual *h* nominate individual *j,* then over time individual *i* was more likely to nominate individual *j*. The negative degree-related parameters, indegree popularity ($\theta = -0.533$, $SE = 0.113$, $p < 0.001$) and outdegree activity ($\theta = -0.306$, $SE = 0.077$, $p < 0.001$), indicate that there was a tendency towards relative egalitarianism in both indegree and outdegree within the network, such that an individual's previous degree did not substantially increase their future degree. This suggests that acts of cooperation were relatively evenly distributed throughout the network.

5.3.2. Actor Covariate Effects on Cooperation Dynamics

Individuals were highly likely to form cooperative partnerships with their close kin ($\theta = 0.484$, $SE = 0.092$, $p < 0.001$). The positive alter parameter for body size and strength ($\theta = 0.015$, $SE = 0.006$, $p = 0.01$) indicates that actors nominated those who were physically larger and stronger as cooperation partners. Results show that there was no significant relationship between physical size and strength and outdegree nominations, nor was there a tendency for actors to selectively cooperate with those similar to themselves in physical size and strength. Income did not relate to indegree nominations of cooperation partners but had a marginally significant effect on an actor's outdegree nominations ($\theta = 0.032$, $SE = 0.018$, $p = 0.079$), with those high in income being marginally more likely to nominate others. Results further indicate that there was a

tendency for actors to preferentially select those similar to themselves in income as cooperation partners ($\theta = 0.278$, $SE = 0.132$, $p = 0.039$). There was a marginally significant tendency for older individuals to receive higher numbers of cooperation partner nominations ($\theta = 0.007$, $SE = 0.004$, $p = 0.057$), but they were less likely to nominate cooperation partners themselves ($\theta = -0.012$, $SE = 0.004$, $p = 0.006$). There was no tendency for individuals of similar age to nominate each other as cooperation partners.

5.3.3. The Effects of Status on Cooperation Dynamics

We find support for our prediction regarding the effect of status on cooperation network dynamics. Results show that there was a significant tendency for those perceived high in status to be nominated as cooperation partners ($\theta = 0.059$, $SE = 0.028$, $p = 0.036$). However, there was no significant tendency for status to impact outdegree nominations, nor was there selection-based homophily according to status.

Cross-sectional analysis of Tsimane men's cooperation network in another community is consistent with our longitudinal results. Status associates with higher indegree and lower outdegree nominations. See SI for specifics of this additional cross-sectional network analysis.

5.3.4. The Effects of Cooperation on Status Dynamics

As shown in Table 1, there was a significant amount of change in status over time, with change in status peaking between period 1 and 2 ($\theta = 6.697$, $SE = 1.638$, $p < .001$), however the difference between periods is not substantial (status rate period 2-3: $\theta = 5.620$, $SE = 1.218$, $p < .001$). The linear and quadratic shape effects indicate the basic trajectory of status over time,

suggesting that there is some non-linear change in status over time. However, neither effect was significant. The positive total alter estimate indicates that the combined statuses of an actor's cooperation partners had a positive effect on their own status ($\theta = 0.036$, $SE = 0.018$, $p = 0.05$), while controlling for all other effects within the model. An actor's status rises to become similar to that of their cooperation partners. Neither age nor size and strength impacted status dynamics. Income had a marginally significant effect on status dynamics ($\theta = 0.040$, $SE = 0.021$, $p = 0.058$), with high values in income increasing an actor's status.

5.4. Discussion

Using a novel social network approach, we provide the first longitudinal evidence in a traditional human society that inter-individual differences in social status structure the formation of cooperative partnerships, and that networks of cooperation contribute to the acquisition of status over time. Furthermore, status motivates cooperation independent of direct reciprocity and kin assortment. We found larger effects on cooperative tie formation from kinship and reciprocity than from either status or income, which accords with previous cross-sectional social network analyses of cooperation in traditional societies (Lamelera: Nolin 2012; Mayangna/Miskito: Koster and Leckie 2014; Mpimbwe: Kasper and Borgerhoff Mulder 2015; rural India: Power 2017; Nunavik: Ready and Power 2018). The observed similarity across previous studies in effect sizes despite large variation in network density (<0.01–0.39) and average degree (3.4–13.1), and in the present findings over time, indicates that these multiple processes may concurrently drive cooperation across disparate socio-ecologies.

Among the Tsimane, men who are respected and influential in community decision-making (i.e. high status) were more likely to be nominated over time as sharing food or assisting in hunting, fishing, logging, and horticultural labour. This result replicated in a cross-sectional analysis of Tsimane men in a second community. One explanation of these results is that higher status Tsimane men are more likely to share food and seek out cooperation opportunities with diverse community members. Political influence may hinge on maintaining coalitional support via generosity (Blau 1964) and widespread social networking. Previous work with the Tsimane found that politically influential men have reputations for generosity, whose effect on influence is largely mediated by coalitional support (von Rueden et al. 2008). But why seek respect or political influence in this relatively egalitarian context? Immediate benefits include resolving conflicts or steering community debates in directions that, while favourable to the community, are particularly favourable to oneself or family members. Among the Tsimane, these debates often concern the rights of households to sell timber from community forest, contracts with NGOs and local government, and conflicts over arable land, sexual jealousy, adultery, theft, and other conflicts. Longer-term benefits include lower stress (von Rueden et al. 2015a) and reproductive gains within and outside marital unions (von Rueden et al. 2011), which may be due to enhanced mate value and greater social support for one's family during periods of particular need, such as illness (Gurven et al., 2000; Sugiyama and Sugiyama, 2003).

Independent of their generosity, high status individuals are likely to be desirable as cooperation partners. Lower status individuals may anticipate access to information (Henrich & Gil-White 2001) or coalitional support that may increase their own status, and cooperation with high status individuals may more effectively broadcast prosociality or other desirable attributes. A previous

study of adults in an industrialized society found that individuals are more generous with better-connected members of their social network (Curry and Dunbar, 2011). Individuals who engage in cooperation with higher status individuals may also mimic their prosocial behaviours (Henrich et al. 2015), which increases similarity in prestige and thus in status. Despite our finding that higher status Tsimane men are no more likely to report others as cooperating with them, we find evidence that cooperation with higher status individuals increases one's own status. The acquisition of social status is a function of social connectedness to high status group members.

The effects of status on cooperation and cooperation on status are independent of the kinship of cooperators and other attributes of Tsimane men, including their age, body size and strength, and income. Older men nominated fewer cooperation partners, which may reflect increasing concentration of cooperation within the extended family as older men's productivity and mobility wane. Size and strength associate with political influence in the Tsimane (von Rueden et al. 2008), which may be due to their contribution to leader charisma (von Rueden et al. 2015b) and coordination ability (von Rueden et al. 2014). However, body size and strength predict acquisition of cooperation partners independent of Tsimane men's status, perhaps because physical formidability is desirous in an ally in the event of conflict. Size and strength may also associate with production skill, as is the case for hunting ability in other traditional societies (Apicella 2014).

Tsimane cooperation partners tend to assort based on income, but not on status or the other attributes we evaluated. Such income homophily may be a signal of incipient stratification by income (David-Barrett & Dunbar 2014), in a society whose exposure to the market economy has

accelerated in recent decades. In contrast, cooperation dynamics may be helping sustain relative egalitarianism in Tsimane men's political status, due to cooperation among status dissimilar men who subsequently influence each other's statuses. Political egalitarianism need not depend primarily on coordinated levelling, as is often emphasized (Boehm 1999). When status diffuses through cooperative relationships, the otherwise self-reinforcing nature of status is kept in check (Bothner et al. 2010).

In general, the present findings suggest that models of the evolution of cooperation should consider (1) the networked structure of human cooperation as well as (2) the relative status of cooperators. Furthermore, our findings highlight the importance of longitudinal observational approaches, which provides greater external and ecological validity that experimental designs, and can fully parse the selection and influence processes driving homophily in networks (Steglich, Snijders & Pearson, 2010). While mathematical models, cross-sectional field studies, and experimental evidence have suggested that individuals selectively assort with cooperation partners who display similarity in cooperativeness (i.e. Apicella et al., 2012; Fu et al., 2012; Di Stefano et al., 2015), the methodological paradigms rarely parse effects of network selection and network influence on actor similarity. Cooperative ties may influence cooperation independent of tie selection: cooperation can increase or decrease via social influence (Fowler & Christakis 2010; Jordan et al. 2013). Among the Tsimane, similarity in status between cooperators is not caused by individuals initially choosing others who are of similar status, but rather may result from the transmission of status through the cooperation network.

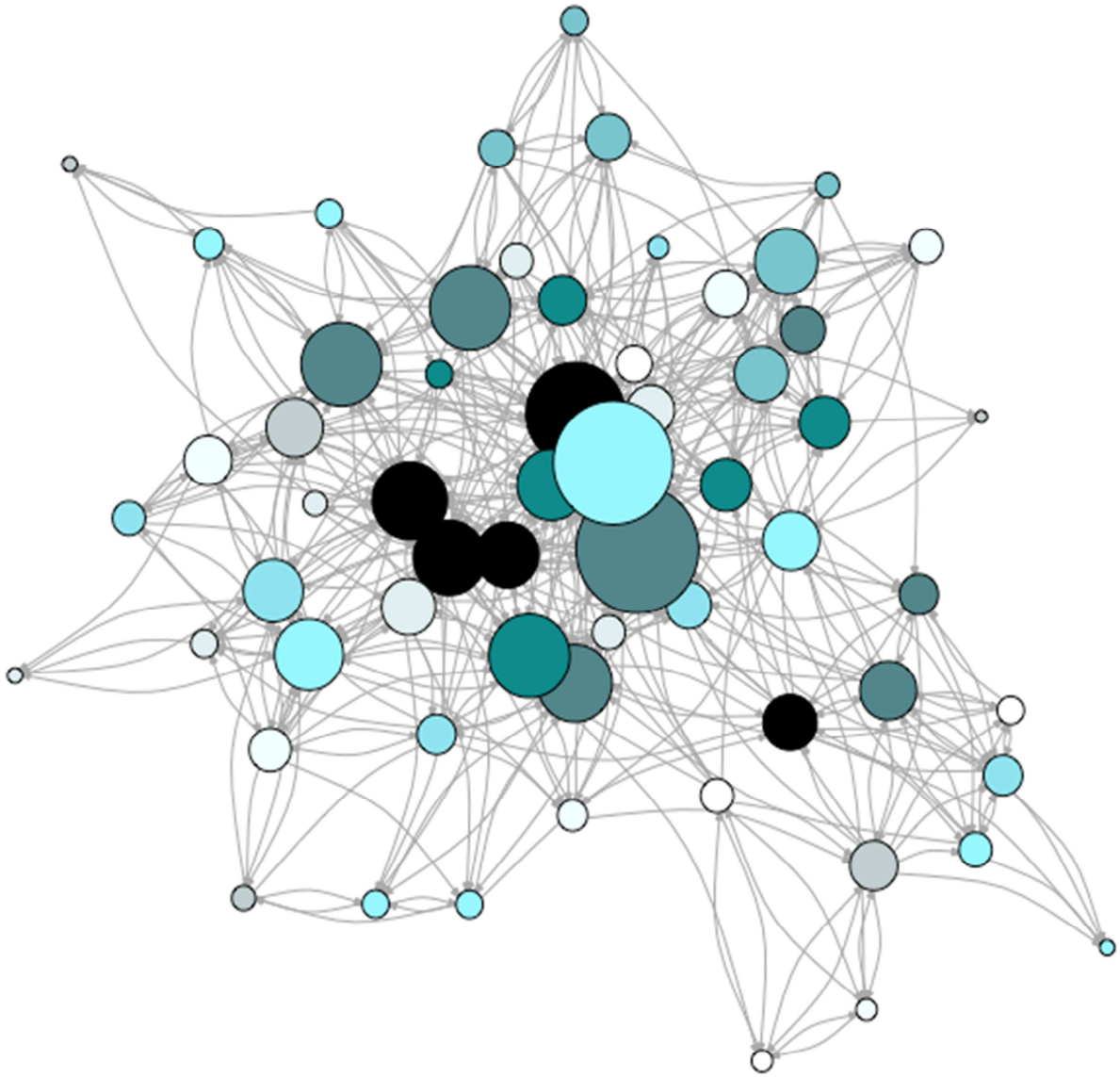
Across human societies, socio-ecological variation in the sexual division of labour, subsistence strategies, mobility, monopolizability of material wealth, community size and density, and other factors should pattern cooperation, status hierarchy, and their dynamic interaction. In some contexts, status hierarchy may be at odds with cooperation (Cronin et al. 2015). However, status in any human organization or society is unlikely to be gained or maintained without demonstrating value to others. Sometimes status-motivated cooperation can be highly competitive or overtly self-aggrandizing. In more stratified small-scale societies, chiefs and Big Men sponsored lavish feasts or gift exchanges, not only to signal their personal qualities but also to generate indebtedness and reveal others' weaknesses (Hayden 1995). The present study of the Tsimane provides a fruitful platform for future longitudinal studies in other societies, to determine how particular socio-ecological factors contribute to the relationship between cooperation and social status, and to infer the evolution of that relationship over human prehistory.

Figure 1a: Two Tsimane men returning from a hunt. Photo credit: Chris von Rueden.

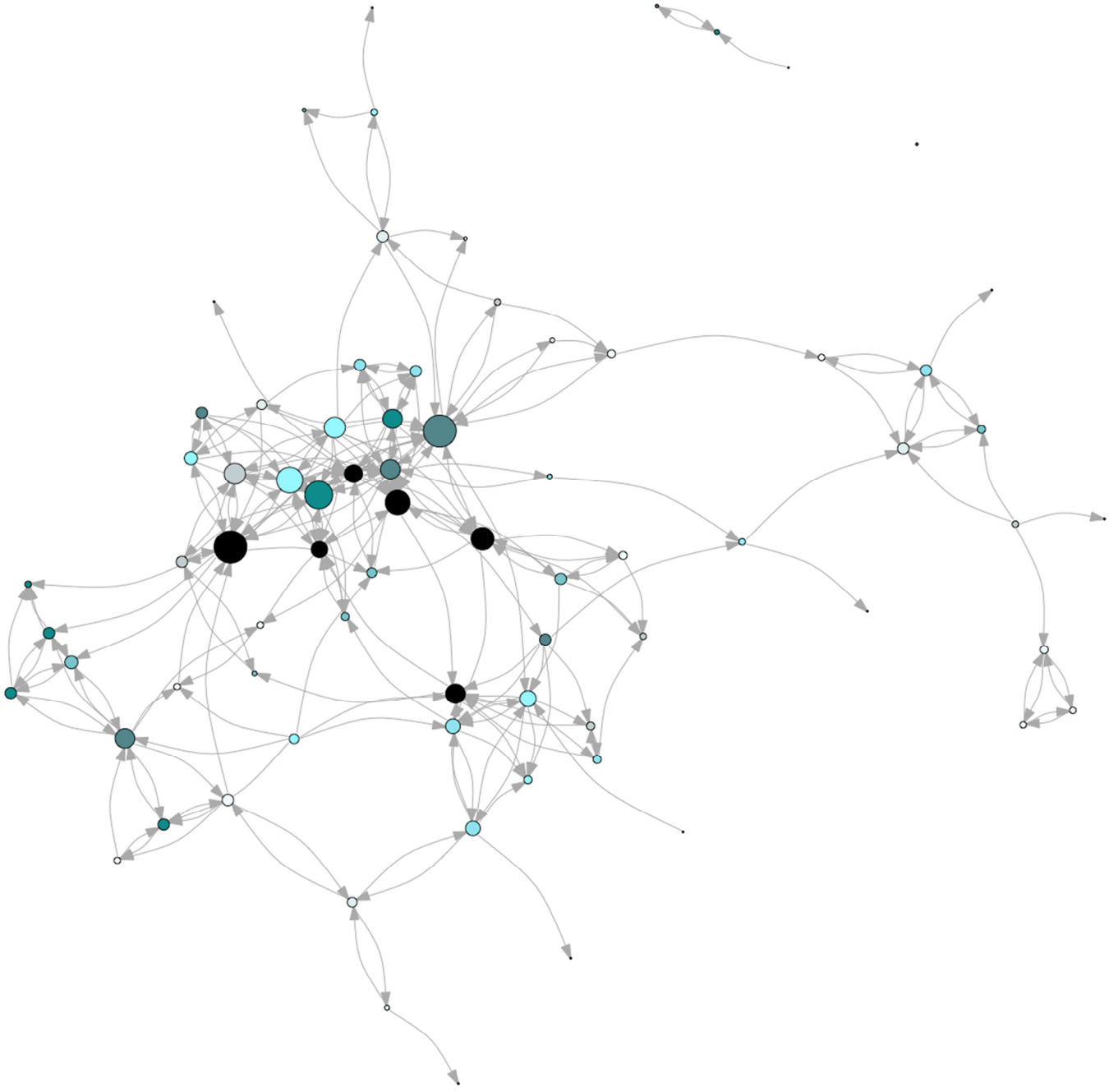
Figure 1b: a Tsimane man helping resolve a dispute over land, which is illustrative of largely informal way in which political influence operates in this society. Photo credit: Chris von Rueden.

Figure 2a-c: cooperation network over time. The cicles (nodes) represent individuals within the community. The size of these nodes was dependent on their indegree nomination, the more nominations they received, the larger the node. The grey lines between them representing the cooperation ties. Arrows indicte the direction in which the nomination was made. The gradient of blue represents the node's level of prestige, with the gradient being darker for higher levels of prestige.

a.



b.



C.

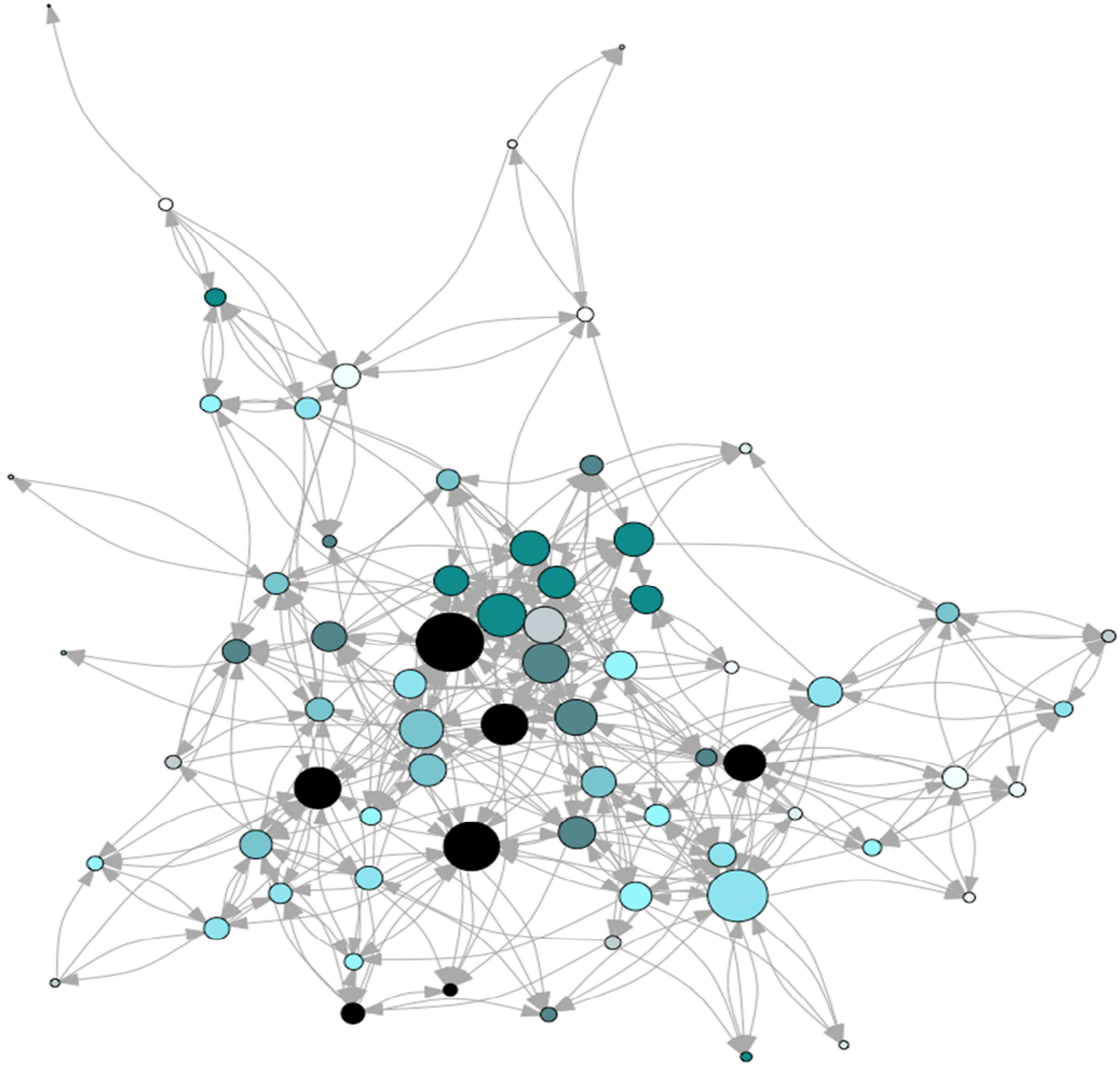


Table 10

Parameter estimates, standard errors and odds ratios for the network-behaviour dynamics of food and labour sharing and prestige.

Parameter	Estimate (θ)	Standard Error	Odds Ratio (OR_	t value (p value)
Network Dynamics				
Cooperation rate (period 1)	37.168***	8.672	NA	4.286 (<.001)
Cooperation rate (period 2)	11.023***	1.104	NA	9.986 (<.001)
Outdegree (density)	-0.270	0.347	0.763	-0.780 (.438)
Reciprocity	1.550***	0.121	4.711	12.819 (<.001)
Tendency towards transitivity [a]	1.422***	0.098	4.145	14.537 (<.001)
Indegree popularity (sqrt)	-0.533***	0.113	0.587	-4.699 (<.001)
Outdegree activity (sqrt)	-0.306***	0.077	0.736	-3.973 (<.001)
Main effect of kinship	0.484***	0.092	1.623	5.286 (<.001)
Status alter	0.059*	0.028	1.061	2.138 (.0359)
Status ego	0.016	0.027	1.016	0.572 (.569)
Status similarity	0.272	0.216	1.313	1.259 (.212)
Physical strength and size alter	0.015**	0.006	1.015	2.621 (.011)
Physical strength and size ego	0.000	0.007	1.000	-0.030 (.976)
Physical strength and size similarity	0.075	0.257	1.077	0.291 (.772)
Income alter	-0.024	0.016	0.976	-1.506 (.136)
Income ego	0.032†	0.018	1.033	1.782 (.079)
Income similarity	0.278*	0.132	1.321	2.105 (.039)
Age alter	0.007†	0.004	1.007	1.921 (.057)
Age ego	-0.012**	0.004	0.988	-2.837 (.006)
Age similarity	0.124	0.237	1.132	0.523 (.603)
Behaviour Dynamics				
Status rate (period 1)	6.697***	1.638	NA	4.090 (<.001)
Status rate (period 2)	5.620***	1.218	NA	4.615 (<.001)
Status linear shape	-0.019	0.077	0.825	-0.251 (.803)
Status quadratic shape	-0.025	0.017	NA	-1.451 (.151)
Status total alter	0.036*	0.018	1.036	2.017 (.047)
Effect from Physical strength and size	0.003	0.008	1.003	0.350 (.727)
Effect from income	0.040†	0.021	1.041	1.923 (.058)

Effect from age	-0.002	0.005	0.998	-0.447 (.656)

[a] Tendency towards transitivity was measured using the geometrically weighted shared edgewise partners effect (GWESP), which has an $\alpha = .69$. For further elaboration of the effect, see SI.

† $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$

5.5. Supplementary Information

5.5.1. Photo Ranking of Status

Each ranker evaluated the photos with no one else present but CvR. The rankers were made aware of the confidentiality of their individual rankings. Verbal instructions were translated into the Tsimane' language from Spanish and then, as a test of the accuracy of translation, back-translated into Spanish by Tsimane' men from other communities.

To select the photo arrays presented to rankers, matrices based on different projective planes were used in different villages and at different waves. We used a matrix whose number of unique values best corresponded to the number of adult men (>21 yrs) to be ranked. For example, a matrix based on the projective plane of order 9 (containing 91 unique numbers) was used in the final wave of data collection, in which 89 adult men were ranked, in addition to two males not quite 21 years old. Based on the matrix, each man was ranked ten times, each time in an array of ten photos. Thus, each man could receive a status score ranging from 10 (lowest) to 100 (highest). For comparison, photo-ranked scores in each village and at each wave were transformed to match in range.

5.5.2. Factor Analysis

Our analysis of status, income, and the size/strength measures as distinct attributes of actors is supported by a maximum likelihood factor analysis with promax (oblique) rotation. Included in the analysis were the two photo-ranked status measures, income, height, weight, and upper body strength from the first wave of data collection. The factor analysis was suitable for the items presented, with a Kaiser-Meyer-Olkin's measure of sampling adequacy of 0.60 and a significant

Bartlett's test of sphericity ($\chi^2(15) = 109.21, p < 0.001$). Furthermore, the communalities between most factors were above the recommended value of 0.3, whilst upper body strength was 0.293 and income 0.169. All diagonals within the anti-image correlation matrix were above the recommended value of .5.

We extracted two correlated latent factors. As shown in SI Table 1, influence and respect loaded highly and positively onto the first factor, while the size and strength measures loaded positively onto the second factor. Although income loaded onto the status factor, it did not meet a minimum loading of 0.4 and was thus retained as a covariate apart from status and the size/strength measures. The status and size/strength factors were correlated (r = 0.37) and had eigenvalues of 2.75 and 1.23, respectively. The extracted factors accounted for 67% of the total variance (46% by status and 21% size and strength).

Given the results of the factor analysis, and in order to limit multicollinearity, we analyzed status as the average of influence and respect, and we analyzed height, weight, and upper body strength as their sum.

5.5.3. Network Descriptives

After censoring for individuals present in only one time wave, the composition of the cooperative partnership network initially comprises 60 actors, increases to 74 actors in time wave two and falls to 70 actors in the final time wave. The average number of cooperation partner nominations ranged between 3.4 and 7.8. The Jaccard index, a measure of tie stability between time waves, indicated that the network was relatively stable despite the significant time that

elapsed between waves. 20.5% of ties remained the same between time wave 1 and 2, and 30.1% remained the same between time wave 2 and 3. Notably, the network at time wave 2 shows reduced density, which may correspond with the major flooding and crop loss that occurred that year (Trumble et al., 2018). Men may have concentrated cooperation with relatives, due to mobility constraints from the flooding or insufficient food to share widely. Cross-culturally, the frequency of unpredictable food-destroying natural hazards associates with increased restriction of food-sharing to relatives (Ember et al. 2018).

5.5.4. Covariate Descriptives

To fit the current data requirements for SAOMs (See Ripley et al., 2018), covariates were transformed into ordinal percentile rankings with 10 levels that were approximately equally distributed. This transformation ensured that 1 encompassed the lowest scorers (the 10^{th} percentile) and 10 the highest scorers (the 90^{th} percentile). Kinship was treated as an undirected network, where binary edges within the network indicated whether the respective dyad were kin (indicated by 1) or non-kin (indicated by 0). See SI Table 2 for descriptive statistics for all covariates included in the SAOM.

5.5.5. Stochastic Actor-Oriented Model (SAOM) Description and Specification

SAOMs estimate latent temporal changes in networks and behaviours as outcomes of a sequence of decisions made by the actors that comprise the networks (for further elabouration and mathematical description see Ripley et al., 2018; Snijders 2001, 2009, 2016; Snijders, Steglich & Schweinberger 2007). To do this, SAOMs use data from an initial observed time point as a starting point for the simulation and estimation of the changes that amount to the final observed

data. Change is assumed to occur in continuous time through a Markov process, and, unlike other longitudinal network models (i.e. Temporal Exponential Random Graph Models, for a comparison see Block et al., 2017), actors are given agency and are assumed to control their outgoing ties through a succession of steps (Snijders, 2001). The opportunities for actors to make such changes are decomposed into the smallest possible step, termed a microstep, and is measured by a rate function (Snijders, 2009). During a microstep an actor is randomly selected and has the opportunity to create, terminate or maintain a tie within the network. When presented this opportunity for change, an actor evaluates all of their possible choices given the composition of the current network, weighting certain choice based on endogenous structural processes (i.e. reciprocity and transitivity), and exogenous mechanisms that may make a certain choice optimal (i.e. to cooperate with kin). These factors that may be driving the change are measured using an objective (or evaluation) function. Actors aim to maximize their objective function and, after assessing all possible choices, the actor will make the optimal choice (with a small amount of randomness: Snijders et al., 2010). Thus, positive parameter estimates in the models indicate that a parameter makes a positive contribution to the objective function and therefore increases the average tendency for actors to create and maintain ties. Negative parameter estimate suggest the converse. Convergence of the model indicates that the parameter estimates are able to very closely simulate the actual measured networks and behaviours.

We specified our SAOM using the recommended stepwise procedure to avoid model over-specification (Ripley et al., 2018). An initial base model was specified and included only elementary endogenous structural effects that are inherent in the development of networks (i.e. outdegree and reciprocity) and change in behaviours (i.e. shape effects). Score-type tests of

further endogenous and exogeneous mechanisms were included in the base model to assess whether inclusion of the parameter made a unique contribution to the objective function and substantially improved model fit. In the score-type tests the parameter being assessed for inclusion is fixed to zero in the model and is then estimated. If the parameter's estimate is significantly different from zero then it would make a substantial impact and should be included within the full model. A full model was then specified and included all parameters that achieved an $\alpha < .05$ in the score-type tests. The parameters included in the final model are described in detail below. See SI Table 3 for a mathematical and graphical description of all included effects.

Within-Network Effects. Five effects were included to capture and control for the structural tendencies of the cooperation network dynamics. The first, outdegree or density, measured how selective individuals were in choosing cooperative partners. The tendency to reciprocate cooperative partnerships and to form transitive groups (i.e. if $i \rightarrow j$ and $j \rightarrow h$, then $i \rightarrow h$) were also included. Two-degree related effects, indegree popularity and outdegree activity, were included to capture the tendency to differentiate in degree, which assessed whether an actor's anterior indegree/outdegree predicted their future indegree/outdegree.

Covariate Effects. A total kinship (both affinal and consanguineal kin) network was modelled as a binary dyadic varying covariate, and one effect, assessing its direct association (i.e. how the presence of a kinship tie directly impacted the presence of a cooperation tie), was included in the model. An ego, alter and similarity effect were included to test our hypotheses regarding the impact that status has on cooperation dynamics. The ego effect measures the impact of the covariate on outdegree nominations, thus a positive ego estimate suggests that the covariate has a

positive contribution to the creation or maintenance of outgoing cooperative partnership ties. The alter effect assesses whether covariate impacts indegree nominations, with a positive estimate suggesting that the covariate has a positive contribution to the creation or maintenance of incoming cooperative partnership ties. The similarity effect captures the selection of cooperative partners based on similarity in the given covariate**.** Ego, alter and similarity effects were also included in the model to assess how physical strength and size, income and age affected choice in cooperative partners.

Status Dynamics. We included the total alter effect to assess our hypotheses about the effects of the cooperation network dynamics on status. The total alter effect measures how an actor's cooperative partner's total value in status influences the actor's status. A positive estimate would thus suggest that, if an actor's cooperative partners are high in status, the actor's status would increase. Several effects were also modelled to fully partial the influence of cooperation on status. The first two, linear and quadratic shape effects, capture the linear trajectory of status and the feedback effect of status on itself, respectively. The main effects from physical strength and size, income and age on status were also controlled for.

5.5.6. Exponential random graph model (ERGM) description and results

To assess the reliability of the SAOM results, an exponential random graph model (ERGM) was conducted on comparable cross-sectional data in a second Tsimane village. ERGMs assess the probability of tie formation in a manner similar to generalized logistic models and allow for the inclusion of endogenous (structural) and exogenous (covariate) parameters that impact the network at an individual (actor/node) level, the dyadic (partner) level and network (group) level.

For detailed outlines of ERGMs see Robins et al. (2007), Lusher, Koskinen & Robins (2013) and Snijders et al. (2006).

The ERGM was conducted in the statnet suite of packages in R (v.: R Core Development Team 2014). The model was built using the guidelines by Goodreau et al. (2007) & Morris et al. (2008). The model includes an edges parameter, which is analogous to the outdegree of our SAOM, a reciprocity parameter and a parameter assessing the tendency to form transitive groups (GWESP: which had a decay of 0.1 and was not fixed). We included node covariate effects to assess the impact that status, income, physical strength and size, and age had on cooperative tie formations. Directed terms (node indegree/node outdegree) were specified as the cooperation network was directed. An edge covariate effect was specified to test the impact that kinship had on cooperative ties. See SI Table 4 for covariate descriptives.

The final model reported is the most comparable to our SAOM and has the best fit. The model has an MCMC sample size of 40,000 with a burn-in of 20,000 and an interval of 800. There is no sign of model degeneracy and there is adequate goodness-of-fit. We also ran the ERGM in MPNet (Wang, Robins & Pattison, 2006) to ensure that there were no differences in results between our SAOM and ERGM due to the slight differences in estimation procedure between packages. There were no qualitative differences in results between the packages.

Results from the ERGM provide a cross-sectional replication of our SAOM (see SI Table 5). The structural processes have a comparably large impact on cooperation ties to our SAOM, with a negative edges parameter (θ = -5.22, SE = 0.800, p <0.001), there being a strong tendency for

reciprocity (θ = 1.442, SE = 0.194, p <0.001) and transitive groups (θ = -0.453, SE = 0.045, p <0.001). Kinship had a substantial relationship on cooperation ties (θ = 1.755, SE = 0.092, p <0.001). Status had a positive relationship with indegree ties (θ = 0.051, SE = 0.019, p = 0.007) and a negative relationship with outdegree ties (θ = -0.060, SE = 0.018, p <0.001). This indicates that those high in status were nominated more as cooperators, and they were less likely to nominate cooperative partners. A similar relationship was found between physical strength and size and cooperation, with those physically stronger and larger receiving more indegree nominations (θ = 0.027, SE = 0.007, p <0.001) but being significantly less likely to send outdegree nominations (θ = -0.022, SE = 0.008, p = 0.005). Income had a marginally significant relationship with outdegree nominations (θ = 0.037, SE = 0.019, p = 0.052), with those higher in income nominating more cooperators. Age had no significant relationship with cooperation.

Table 11.

Factor analysis of status and actor covariates from first wave of data collection in village 1

Table 1.
structure matrix

Item	Factor	
	1	2
Influence	.999	.349
Respect	.803	.450
Income	.398	.112
Height	.219	.987
Weight	.426	.629
Upper body strength	.330	.629

Note. $N = 72$. GOF: $\chi^2(4) = 4.234$, p = .375.

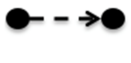
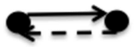
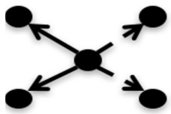
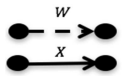
Table 12.
Descriptive statistics for actor attributes in Village 1.

Variable	Mean (SD)	Range (Min-Max)	Density
Status T_1	5.47-(2.842)	9 (1-10)	
Status T_2	5.449 (2.608)	9 (1-10)	-
Status T_3	5.535 (2.772)	9 (1-10)	-
Status T_4	6.054 (2.619)	9 (1-10)	-
Physical Strength & size T_1	104.871 (9.130)	45.67(80-125.67)	-
Physical Strength & size T_2	104.473 (7.292)	35.33 (86.7 – 122)	-
Physical Strength & size T_3	107.556 (8.109)	44.83 (89.3 – 134.1)	-
Income T_1	5.540 (2.860)	9 (1-10)	-
Income T_2	5.428 (2.691)	9 (1-10)	-

Income T_3	5.653 (2.752)	9 (1-10)	-
Age T_1	36.07 (12.791)	47 (21-68)	-
Age T_2	35.159 (12.352)	51 (21-72)	-
Age T_3	38.189 (12.705)	56 (21-77)	-
Kinship T_1	10.733[a]	22(0-22)[b]	0.091
Kinship T_2	8.865 [a]	24 (0-24)[b]	0.061
Kinship T_3	10.595 [a]	22 (0-22) [b]	0.076

Note.
[a] Mean degree.
[b] Range of degree (min degree – max degree).

Table 13.
Network and Covariate effects included in the objective functions of the SAOM model.

Effect	Mathematical Expression	Graphical Expression	Interpretation
Structural Network Effects			
Out-degree (density)	$\sum_i x_{ij}$		The average tendency for actors to create outgoing cooperation ties.
Reciprocity (recip)	$\sum_j x_{ij}\, x_{ji}$		The average tendency actors to reciprocate cooperation ties.
Transitive group formation (gwespFF)[a]	$\sum_{k=1}^{n-2} x_{\ ij}\, e^{\alpha}\{1-(1-e^{-\alpha})\sum_{h=1}^{n} x_{ih}x_{hj}\}$		The average tendency for closure in the cooperation network.
In-degree Popularity (inPopSqrt)	$\sum_j x_{ij}\sqrt{\sum_h x_{hj}}$		The average tendency for actors to attract greater incoming cooperation ties from alters due to their high current in-degree ties.
Out-degree Activity (outActSqrt)	$\sum_j x_{ij}\sqrt{x_i +}$		The average tendency for actors to create out-degree cooperation ties due to their high current out-degree ties.
Covariate Effects			
Main effect (centered) of the dyadic covariate (X)	$\sum_j x_{ij}(w_{ij}-\bar{w})$		The effect of having a kinship tie with an actor in the kinship network (*W*) on forming a tie with that actor in the cooperation network (*X*).
Covariate sender (egoX)	$\sum_j x_{ij}\, v_i x_{i+}$		The tendency for actors with high values on a covariate to create greater out-degree ties.
Covariate receiver (altX)	$\sum_j x_{ij}\, v_j$		The tendency for actors with high values on a covariate receive great in-degree ties.

Covariate Similarity (simX)	$\sum_j x_{ij}\ sim_{ij}^{v} - \widehat{sim^{v}}$		The tendency for actors to create ties with alters who have similar values to them on a given covariate.
Effects on status dynamics			
Linear shape (linear)	z_i		Expresses the basic drive towards high values on status.
Quadratic shape (quad)	z_i^2		Represents the feedback effect of status on itself.
Total alter (totAlt)	$z_i\left(\sum_j x_{ij} z_j\right)$		The tendency for actors to increase their status due to the influence of the sum of their alters' statuses.
Main covariate effect (effFrom)	$z_i\, v_i$		The main effect of an actor's score on a given covariate on their status (status is centered and has an overall mean of 0).

Table 14.
Descriptive statistics for actor attributes in village 2.

Variable	Mean (SD)	Range (Min-Max)	Density
Status	5.480 (2.863)	9 (1-10)	
Physical Strength & size	102.384 (7.224)	9 (1-10)	-
Income	5.510 (2.849)	9 (1-10)	-
Age	38.22 (13.179)	9 (1-10)	-
Kinship	12.989[a]	34(0-34)[b]	0.074

Note.
[a] Mean degree.
[b] Range of degree (min degree – max degree).

Table 15.

Parameter estimates, standard error and p-values for ERG model assessing village 2.

Parameter	Estimate	*SE*	*p*-value
Edges	-5.22***	0.8	<0.001
Mutual (Reciprocity)	1.442***	0.194	<0.001
Geometrically weighted edgewise shared partners	0.453***	0.045	<0.001
Main effect of kinship	1.755***	0.092	<0.001
Status alter	0.051**	0.019	0.007
Status ego	-0.060***	0.018	<0.001
Income alter	0.004	0.019	0.825
Income ego	0.037†	0.019	0.052
Strength alter	0.027***	0.007	<0.001
Strength ego	-0.022**	0.008	0.005
Age receiver	-0.003	0.004	0.503
Age sender	0.002	0.004	0.714
Null deviance = 10857, *df* = 7832			
Residual deviance = 2684, *df* = 7819			
AIC = 2710			
BIC = 2801			

† $p<0.10$ * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

6

General Discussion

The current body of research proposed that two profiles, prestige and dominance, form two components of the dynamic system of human social hierarchy. Through this approach, the current research provides an important theoretical contribution to the extant body of literature: it integrates the simultaneous effects of time and social structure into the dual model of social hierarchy. The theoretical integration of how time and structure allowed the current research to advance three overarching hypotheses: 1) That prestige, dominance and social rank will fluctuate over time, with changes in one of these processes will impact change in the other; 2) That social hierarchies are embedded in social networks, which are as likely to be a consequence as to be a cause of differences in prestige and dominance; 3) There are distinct social networks that relate to cooperation among humans, which are multiplex (i.e. ties in one network impact ties in the other) and inherently linked to social hierarchy.

To uncover whether the relationships between prestige, dominance and social rank displayed dynamic change over time, Chapter 3 provides a longitudinal extension of existing cross-sectional paradigms that assess social rank in organic, collaborative groups (Anderson & Kilduff, 2009a; Cheng et al., 2013; Ridgeway, 1987; Ronay et al., 2012). The present research captured peer-perceptions of prestige, dominance and social rank among student task groups from the initial point of group formation through to the end of a 16-week semester, when the task was complete. Results indicated that prestige, dominance and social rank were related, dynamic processes that exhibited smooth non-linear change over time. Findings revealed that prestige had a positive impact on social rank and that the relationship between the two processes was bidirectional, with social rank concurrently increasing an individual's prestige over time. In contrast, findings in Chapter 3 indicated that, whilst dominance was effective in increasing social

rank during the initial point of group formation—replicating previous findings (Cheng et al., 2013)—the relationship between dominance and social rank diminished after this point, with neither process having a substantial impact on the other over time. Results from Chapter 3 further highlight that prestige and dominance are distinct profiles (Cheng & Tracy, 2014; Henrich & Gil-White, 2001; Maner, 2017), as neither impacted the other over time and the processes had divergent longitudinal trajectories with social rank over time. Overall, the results outlined in Chapter 3 confirm hypothesis 1 and show that prestige, dominance and social rank are dynamic processes.

Chapter 4 delivered an examination, and offered evidence in support, of hypotheses 2 and 3. The study examined how prestige, dominance, instrumental network ties and expressive network ties simultaneously impact one another. To assess the proposed relationships between the four components, the study captured peer ratings of prestige and dominance, and peer nominations of work-related advice (instrumental network ties) and friendship (expressive network ties) among North American undergraduate students. Results demonstrated that those high in prestige were nominated more as advisors and were less likely to ask for advice, while dominance has no relationship to the selection of advisors. Findings further suggested that being nominated as an advisor increased an individual's prestige over time and that the prestige of an individual's advisors increased an individual's prestige overtime. In contrast, the presence of an incoming advice ties decreased and individual's dominance. The present findings suggested that prestige did not have a significant impact on nominating or being nominated as friends, whilst those high in dominance were marginally less likely to be nominated as friends over time. Furthermore, the multiplex models presented in Chapter 4 indicate that friendship and advice also simultaneously impacted one another. Results suggest that friendship ties led to advice ties

(and vice versa), that advice ties were reciprocated by friendship ties (and vice versa), and that high indegree in friendship caused high indegree in advice, whilst all other actor-level effects where non-significant.

To lend further support to hypothesis 2, Chapter 5 evaluated the impact of prestige status in cooperation networks, operationalized as instrumental support ties through nominations of food-sharing and help with food-production, among the Tsimane hunter-horticulturalists. The study captured the dynamics of peer-ratings of prestige status and these cooperation networks among men in one village across a 12-year period. Results demonstrate that those high in prestige status were nominated more as individuals who shared food and helped with food production but were less likely to nominate others. Similarity in prestige status was observed to be a product of network influence, as opposed to network selection, with the prestige status of those with whom an individual shared a cooperative tie increasing that individual's prestige status. These findings were unique of the impact of physical strength and size, kinship, income, age and endogenous network processes that typically guide cooperation in small-scale societies (i.e. direct reciprocity). Overall, the results of Chapter 5 replicate those relating to prestige status and instrumental network ties found in Chapter 4 using a different domain of instrumental support among a more ecologically valid population and across a longer period of time. Alongside this, those physically stronger and larger were more likely nominated as cooperative partners. While physical strength and size may be associated with dominance (), it may also be associated with prestige () and thus conclusions about the impact of dominance are hard to draw.

Taken together, this body of research delivers the first longitudinal assessment of social hierarchy and offers initial evidence of the complex dynamics between processes of prestige, dominance, social rank and social networks. Through this, the current research provides several contributions—both theoretical and methodological—to the existing literature. The following section briefly surmises these contributions and acknowledges several limitations to the research, which give rise to questions for future enquiry.

6.1. A dynamic model of social hierarchy

The current research builds upon a literature that proposes that individuals gain social rank in human hierarchies through dominance, centred on the ability and willingness to inflict harm on others, and prestige, which is founded by the ability and willingness to confer benefits to others (Henrich & Gil-White, 2001). Individuals may exhibit stable levels of dispositional prestige and dominance, which make them more inclined towards behaviors and interpersonal relationships that broadcast either their ability and willingness to inflict harm or confer benefits. However, these behaviours and relationships display facultative flexibility over time, and potentially between contexts. Natural selection may have favoured more dynamic, proximate behavioural displays that communicate an individual's motivations and dispositions associated with rank attainment. Such behavioural plasticity may be associated with the need to adapt to stochastic temporal or situational changes in ecological pressures invoked by the environment or culture (Baldwin, 1896; Oyama et al., 2001; Reader & Laland, 2002; Richerson, in press; West-Eberhard, 2005).

This contribution provides a fruitful platform for exploring when prestige and dominance are effective in human groups. While prestige and dominance seem to be the core routes to high social rank in human groups, empirical evidence has shown that the profiles—especially dominance—display differing levels of success (Anderson & Kilduff 2009b; Anderson, Srivastava, Beer, et al., 2006; Cashdan, 1980; Lukaszewski et al., 2014; Ridgeway & Diekema, 1989; Kaplan, Hooper & Gurven, 2010; Price & Van Vugt, 2014). The dynamic perspective proposed by the present research provides a number of explanations for these findings. First, social hierarchy, and thus an individual's social rank, are situated in context. That is, it is reasonable to believe that individuals who are high in social rank in one context may not necessarily harbour the traits or express the behaviours that would cause them to be high-ranking in a context has different demands, and thus favours different qualities (Fielder, 1967; Hofstede, 1980; McCann, 1992; Stogdill, 1948, p.65). In sum, there may be context-dependent needs and norms in relation to rank acquisition (Anderson et al., 2015; Ridgeway, 2017).

Second, human groups exhibit several mechanisms that may level the relationship that dominance has with social rank, and these mechanisms take time to develop. Dominance seems significantly related to social rank when collaborative groups are in their nascent stages or are transient (Cheng et al., 2013; Pellegrini & Long, 2003). The efficacy of dominance in such groups may be founded on human's evolved cognitive capacities to extract formidability-relevant information (Sell et al., 2009), in turn making cue of dominance incredibly salient in such groups. However, as shown in Chapter 3, when these groups become more acquainted the relationships between dominance and social rank diminish. When individuals in these groups interact trust between them increases, and individuals are more likely to exchange information

about one another, and the perceived value of group members develops (Baumeister, Zhang & Vohs, 2004; Bert & Knez, 1996; Dunbar, 1996; Feinberg, Willer & Schultz, 2014). In turn, these individuals may be more likely to discuss high dominance counterparts and increasingly dislike them due to the negative impact that dominance may have on them (i.e. physical aggression or verbal abuse) and they may form coalitional groups that sanction the behaviours associated to, and supress, dominance (Boehm, 2009; Boehm & Flack, 2010; Gintis, Van Shaik & Boehm, 2015). Therefore, the current perspective holds that the effectiveness of dominance on social rank in humans is constrained to groups that do not develop such coalitions or normative cultures that supress dominance (Hawley, 1999; Henry et al., 2000; Redhead, 2016), when social rank is formalized and those high in dominance structurally have inordinate power over valued resources (i.e. Magee & Galinsky, 2008), and, as outlined in Chapter 4, when the negative expressive ties that dominance is potentially associated with can successfully produce fear and coercion.

The present research indicates that prestige, on the other hand, may flourish in most human groups over time. As chapter 3 indicates, prestige is more effective in promoting social rank when groups have time to more readily observe more accurate cues to an individual's ability and willingness to confer benefits. These signals to prestige seem to be inherently related to cultural learning (Henrich & Gil-White, 2001; Schniter et al. 2015; Smith et al. 2017), with results from Chapter 4 showing that those high in prestige are nominated more as advisors, that these nominations increase both their prestige and also facilitate the diffusion of prestige within a group. Individuals ask advice to gain knowledge and, by obtaining such knowledge, an individual becomes more able in that domain.

The networks of cooperation that relate to prestige are not relationships that operate in isolation, they are multiplex and have effects on one another. As overviewed in Chapter 4, cooperative relationships involve both acts of instrumental support, such as advice and food sharing, and also expressive relational ties, such as friendships, that create positive affect (Coleman, 1988). In line with previous multiplex analyses (Kwok, Redhead & Brown, *in prep*; Snijders, Lomi & Torló, 2013), these networks have direct impacts upon one another. The present findings indicate that these multiplex relations act as different, but analogous, currencies that individuals may exchange to maintain cooperation.

6.2. Limitations and future questions

The current research has a number of limitations that should be addressed in future investigations. First, a large proportion of data that comprises the current research was collected from North American undergraduate students. This W.E.I.R.D. (Western, Educated, Industrialized, Rich, Democratic) population may not be representative of the populations in which the processes emerged, nor of other contemporary populations (Henrich, Heine & Norenzeyaga, 2010). While this is a limitation, the use of this population allowed data to be drawn from a larger population pool, and many of the current results related to the effects of prestige and dominance and the structural emergence of the social networks are complimentary to findings from small-scale and non-W.E.I.R.D. groups (i.e. Apicella et al., 2012; Garfield & Hagan, in press; Kasper & Borgerhoff Mulder, 2015; Konecna & Urlacher, 2017; Koster & Leckie, 2014; Nolin, 2012; Power, 2017; Power & Ready, 2018; Redhead, 2016; Von Rueden et al., 2008). Given the proposition that dominance may be constrained to certain groups,

comparative cross-cultural future research may be important to unpick when dominance is effective. For example, such comparisons could be between small-scale societies that may have higher levels of intergroup conflict, compared to those with low levels; or between groups that have low levels of density and structural cohesion paralleled to those with high levels. An associated limitation is that, whilst the present findings illuminate that group processes may emerge over time to level the effects of dominance on social rank, it does not directly capture the mechanisms that drive these processes (i.e. gossip, ostracism). Future research that directly measures the emergence and effectiveness of such mechanisms levelling dominance would provide important insight into why dominance is not effective in promoting social rank in some contexts.

A further limitation is that the current research focussed solely on positive network ties and, thus the associations that prestige and dominance have with negative network ties remains unclear. This gap in the literature needs to be filled by future research as evidence suggests that while the frequency of negative ties is much lower than those of positive, their potency is much greater (Labianca, 2013). Alongside this, future research may make further valuable contributions to the field by investigating the multiplex associations between prestige, dominance, negative and positive ties, such as how warfare and allegiances co-emerge in small-scale societies. Through this, future research will provide greater insight into the complex systems that guide rank attainment in humans.

6.3. Concluding remarks

The current research has shown that human social hierarchy is a complex, dynamic system that is embedded in social networks. Through this, the present findings have contributed to the existing literature by demonstrating the dynamic relationships that prestige and dominance have with social rank within the structural systems that characterize human groups.

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