

2004 SFI Proposal of Padgett et al. to NSF program on Human and Social Dynamics

I. Background and Overview

This project assembles a cross-disciplinary (physics, sociology, statistics and history) and international (United States, India, Australia) team to analyze the social production of organizational innovation in Renaissance Florence. The project is built upon the empirical foundation of a powerful, indeed unprecedented historical data set – economic, political and kinship social-cum-organizational networks, traced over a two-hundred-year time span (from 1284 to 1500 A.D.). This data set, coded from original archival documents by Padgett (with significant help from McLean) over a span of fifteen years, will be described below. Under the sponsorship of the Santa Fe Institute, technical experts in social-network statistics (Pattison), in autocatalytic network dynamics (Jain), and in agent-based modeling (Sallach) will be assembled to assist substantive experts (Padgett and McLean) in the production of network models of organizational genesis, fitted to the Florentine data. The technical innovations demanded by the historical materials involve (changing) catalytic and regulatory feedbacks across the reproduction and development of multiple types of social networks.

Renaissance Florence was among the most innovative centers in Western history in its creation of new organizational forms. In the domain of economics, international finance and double-entry bookkeeping was invented in Northern Italy and came to be centered in Renaissance Florence (de Roover 1966, 1974, Goldthwaite 1993, Padgett 2001, Padgett and McLean forthcoming). In the domain of politics, republicanism reemerged in a few of the most prominent northern Italian city-states (Genoa, Florence, Venice), with Florence being particularly creative in its exploration of new electoral mechanisms (Najemy 1982). These Florentine electoral mechanisms later were to become important in the founding constitution of America (Pocock 1975). In the domain of extended family, dowries and the emergence of republican clientage had significant consequences for the restructuring of social elites, social status and social mobility (Brucker 1969, 1977). Such social restructuring created the competitive motivation for now-famous innovations in the production of new art (Baxandall 1988), new political philosophy (Baron 1966), and arguably new psychology (Burckhardt 1878).

Unexplored in the otherwise thorough secondary literature on Renaissance Florence are the causal connections among these extraordinary innovations. Were these simply a remarkable set of historical coincidences or ‘conjunctures’? Or did some sort of heretofore poorly understood ‘social innovation cascade’ occur within this particular city and time, across multiple domains? Padgett’s previous publications on this topic have documented the empirical plausibility of the second conjecture for the two domains of political-party formation (1993) and financial-market formation (2001, forthcoming). Specifying multiple-network feedbacks and possible organizational-form cascades analytically, and then empirically testing the resulting dynamic-network models with Florentine data, is the research goal of this project.

Possible parallels between biological and human social evolution need to be approached with caution, skepticism and discipline indeed (Maynard Smith and Szathmari 1995, Lewontin 1992). However, the possible phenomenological similarity between extraordinary outbursts of human creativity like Renaissance Florence and ‘macro-evolutionary’ events like the Cambrian explosion (Gould 1989, Morris 1998) has not escaped our attention. Sanjay Jain (with informal help from other SFI external faculty

Doug Erwin and Ricard Sole) will explore the insights, as well as the limitations, that existing macro-evolutionary models in biology offer to understanding the Florentine case. No doubt major modeling extensions eventually will be required, especially in the direction of multiple-network feedbacks, but developing a common dynamic-network formal framework will be the first analytic step, already partially attained.

II. Empirical foundation: the Florentine data set

A distinctive feature of this project is the extraordinary quality of and coverage in the underlying data set. To a surprisingly high degree of accuracy, this data set measures the social-network structure of an entire city over two centuries. Fifteen years have gone into its construction, from primary sources in the Florentine archives. The volume of data in the Florentine archives is staggering – far beyond anything else in pre-modern times – for two reasons: (a) Renaissance Florence was ‘the birthplace of financial capitalism’; hence its government, its firms, and its families were unusually literate and numerate. And (b) Florentines self-consciously thought of themselves as historically significant; hence they saved much of their written output, beyond the duration of its instrumental utility. Sampling issues, due both to researcher search procedure and to historical survival of documents, of course remain important. But as an order-of-magnitude estimate, about half of the corresponding ‘historical reality’ of Florentine social and economic networks are captured in this data set. [More precise estimates of sampling coverage, which vary by source, are found in the publications.]

Details of the data contained in this ACCESS relational database are as follows:

A. Population:

(1) Tax censuses. Data from the Florentine head-of-household tax censuses of 1351, 1378, 1403, 1427, 1458, and 1480 have been coded and computerized. The 1427 *catasto* was coded by Herlihy and Klapisch (1985); the 1480 *catasto* was coded by Molho and Kirshner (1994); the rest were coded by Padgett. These censuses contain information on neighborhood residence, tax assessment (wealth surrogates), family structure, and in the case of 1427 much more. Sampling coverage for 1427 and 1480 was 100%. The coding rules for Padgett’s censuses were “all households with last names” plus “all households above certain tax thresholds”. These generated 30%-65% coverage.

B. Kinship:

(1) Marriage. 11,000+ unique marriages were coded from a seventeenth-century marriage registry, called the *Carte dell’Ancisa*, as well as from eighteenth- and nineteenth-century genealogies located in the rare-book rooms of seven American libraries. Most of the dowry contracts, upon which these registries were based, have been lost to fire. These data were analyzed, in preliminary fashion, in Padgett (1994).

(2) Patrilineage descent. 37,000+ father-son and 8,000+ father-daughter relations have been identified, enabling the computerized reconstruction of 1600 genealogies or family trees. “Missing fathers” can and have been identified through this linking procedure. The social evolution of families, over two centuries, can be traced with these genealogical and marriage data.

C. Economics:

(1) Annual banking guild censuses. Annually from 1340 on, and also in 1299, 1300, 1301, 1314 and 1329, the *Arte del Cambio* banking guild required the registration of all banks doing business in Florence. This time-series information has been coded,

providing invaluable information on the changing partnership structure of Florentine banks over time. These data were discussed in Padgett (2001).

(2) Ad hoc business censuses. Annual time series for other industries do not exist, but numerous ad hoc business censuses exist for merchant trading (1355, 1369, 1380-1400, 1427, 1451, 1458), for wool manufacturing (1353, 1382, 1427, 1451, 1458), and for silk manufacturing (1427, 1451, 1462, 1472). The macroeconomic histories of these core export-oriented Florentine industries can be traced through such censuses.

(3) City-wide debts and credits. For tax calculation purposes, the 1427 *catasto* registered all outstanding debts and credits in the entire society at that moment in time. Such an extraordinarily detailed snapshot of financial indebtedness in the society is unique in pre-modern economic history. 15,000+ of these debts have been coded by McLean, about five thousand of which are company-to-company debts. These credit data have been analyzed in Padgett and McLean (forthcoming).

(4) Account books. Selections from the following company account book have been coded: Alberti (1355), della Casa and Guadagni (1458), Capponi (1477), Strozzi (1480). These provide credit samples, to give temporal context to more comprehensive 1427 credit data. Other account books are available in the archives for future coding.

D. Politics:

(1) Political offices. Complete time-series of elected Florentine officeholders, from 1284 to 1500, have been coded from primary sources for the following republican offices: the *Signoria* or city council, the *Mercanzia* or commercial court, and *Cambio* guild consuls. Five guilds' matriculation records have been coded from primary sources. Four other time-series of guild consuls have been copied from Litchfield et al. (2000). Special reform councils and 'grand councils' have been coded from Rubinstein (1966) for the Medici period, when these became politically important. Political office-holding was central to social status and prestige in republican Florence, as well as to political power.

(2) Political factions. From both chronicles and the detailed prosopographical studies of others, political memberships in the following factional splits have been identified: magnate versus popolani (1284-1300), Black versus White Guelf (1310s), Albizzi versus Ricci (1360s), Ciompi revolt (1378), Albizzi versus Medici (1434), 'republican reaction' (1466), Savonarola (1490s). The Albizzi versus Medici data have been analyzed in Padgett and Ansell (1993).

(3) Letters of recommendation. For his dissertation, McLean identified and analyzed 869 letters of elite Florentines to each other, asking political favors of various sorts either for themselves or for their 'friends'. The texts of these letters have been coded not only for egocentric social networks, but also for linguistic content and form. These data have been analyzed, statistically and linguistically, in McLean (1996, 1998). The letters provide invaluable insight into the cultural context, into the interactional and linguistic practices, and also into the daily psychology of Renaissance Florentines. No modeling exercise can ignore the rich micro-motivational information contained in them.

In total, almost 50,000 people are included in the data set – 37,000 males and 11,000 females. Both in the original documents and because of Padgett's selection and linking procedures, this sample is skewed toward Florentines with last names. An extremely high percentage of such people appear in the data set, whereas a much lower percentage of the poor *popolo minuto*, with names like "Giovanni, son of Paolo" are included. In 1351, the percentage of the population with last names was around 25%,

whereas by 1480 this percentage had grown to around 60%. David Sallach and Nick Collier, then employed at the University of Chicago's social science research computing center, aided in the relational design and in the integration of the 80+ tables that comprise this ACCESS data set.

III. Senior Research Personnel

John Padgett, a political scientist at the University of Chicago and a research professor at the Santa Fe Institute, specializes in organization theory, social network analysis, stochastic process modeling and Renaissance history. **Paul McLean**, a sociologist at Rutgers University, specializes in economic and cultural sociology and in Renaissance history. These are the substantive experts in this project. **Sanjay Jain**, a physicist at the University of Delhi and an external faculty member of the Santa Fe Institute, specializes in the dynamic modeling of autocatalytic networks in chemistry and biology. **Philippa Pattison**, a quantitative social scientist at the University of Melbourne, specializes in the algebraic and statistical analysis of social networks. **David Sallach**, a senior scientist at Argonne National Laboratory, specializes in agent-based modeling and in data base design. At the University of Chicago, he created Repast, the well-known agent-based modeling platform. These three are the technical experts in this project.

PAST EMPIRICAL FINDINGS AND FUTURE MODELING PROJECTS

Organizational innovation occurred in Renaissance Florence in three interrelated domains: social, economic, and political. The goal of the research project is firstly to empirically discover and secondly to analytically model the dynamic causal feedbacks among the constitutive social networks that produced these historical innovations. We will now summarize our past empirical findings and outline our current and future modeling strategies for the social, the economic and the political domains, in that order.

IV. Kinship, Elite Structure and Social Mobility

A. Past Empirical Findings

Fundamental to the historical transition from medieval to Renaissance Florence was a transformation in family structure from the solidaristic and closed patrilineages or clans characteristic of medieval Italy to the hierarchical but looser extended families characteristic of Renaissance Florence (Goldthwaite 1968, Kent 1977, Herlihy and Klapisich-Zuber 1985). Much was linked to this transformation in the basic integuments of society: Solidaristic clans were associated with high levels of factional violence in the society (Lansing 1991, see also Shakespeare's *Romeo and Juliet*). Extended-family hierarchical assemblies of nuclear families, on the other hand, were associated with the emergence of a city-wide 'oligarchic' social elite, linked through intermarriage (Molho 1994). Elite solidaristic patrilineages were almost closed castes, floating on a sea of no-family-name workers. Hence in late medieval times struggles for political control in Florence often veered into virtual class warfare. With looser extended-family structures, interlinked first through marriage and later through clientage, channels for social mobility opened up, and class warfare broke down as the middle-classes began to imitate a paler version of the family structure of their status superiors (Cohn 1992). [This was the reason for the rise in percentage of the population with last names, cited above.] If anything the Renaissance society was more hierarchically elitist than ever, but it was an 'open elite' that channeled conflict and violence into status competition (see also Stone 1984, McLean forthcoming). In turn, social mobility and status competition within newly fluid

elites were central to the 'competitive giving' that poured the money of wealthy sponsors into the celebratory products of their artistic and philosopher clients.

Padgett (1994) has traced the timing and structure of these transitions in some detail through his data on the changing Florentine marriage network. Before the Black Death of 1348, elite clans were linked asymmetrically through marriage primarily within neighborhood. As a result, late-medieval Florence was fractured into geographically localized clusters of clans, the clusters in turn being hierarchically arrayed. This marriage-network structure had historical roots in countryside feudalism imported into the city. Each cluster functioned as a political-cum-military alliance, which fought its neighbors. Two historical events shattered this late-medieval marriage system: (a) The Black Death killed 60% of Florence, elite as well as poor. And (b) repression of the Ciompi revolt of wool workers in 1378 restructured the political functioning of marriage. The first event mortally wounded the old system; the second event rebuilt a new one. Through a process of systematically co-opting in marriage the 'lieutenant' clans of the losing Ricci faction which supported the Ciompi, the victorious Albizzi faction destroyed the old guild-corporatist version of republicanism and constructed a city-wide elite oligarchy in its stead. [See Najemy (1982) for the institutional side of this elite-network reconstruction.] Padgett and Ansell (1993) analyzed this "political repression into oligarchic elite formation through marriage cooptation" process in historical detail.

Padgett (1994) also contains valuable clues about marriage-network evolution in the later fifteenth century, under the Medici. Cosimo de' Medici (1434-1464) built half of his political-network machine from a segment of the oligarchic marriage system built by the previous Albizzi regime. (The other half of his centralized political machine was built out of markets and banks.) Through marriage networks, in other words, Cosimo controlled Florentine politics 'backstage' without relying much on overt institutional manipulation. In contrast, Padgett's marriage data reveal that Lorenzo de' Medici (1469-1492) retreated into a self-enclosed and cliquish 'court' in arranging the marriages of the Medici and their allies. Lorenzo abandoned the effectively indirect and outward reaching marriage-network political-control strategy of his grandfather, and therefore was forced to rely on more obviously blunt institutional manipulations instead (Rubinstein 1966). These transparent manipulations led to loss of political legitimacy and ultimately to Savonarola and the fall of the Medici regime, immediately upon Lorenzo's death.

All of this past empirical work points to the intimate causal relationship between marriage, family and politics in Renaissance Florence. Kinship structured the dynamics of political faction formation and thereby the various republican constitutions formed by factional deals. And social elite formation, triggered in politics, trickled back into the (slower) reconstitution of marriage and patrilineage, via the mechanism of social mobility. Organizational innovation, both at the level of family and at the more macro level of social class, was the consequence of dynamic feedback between politics and kinship. Typically such feedback leads to the consolidation and reproduction of mutually reinforcing network structures. Historians characterize such network equilibria as the popolani regime, the guild-corporatist regime, the Albizzi oligarchic regime, the Medici centralized regime, etc. But Florentine history was distinctive, compared to other Italian cities, in the frequency of the sudden and unanticipated 'regime changes' it experienced. The Florentines innovated because they were forced to do so, not because they wanted to.

B. Current and Future Modeling Projects

In the domain of kinship and elite formation, two formalization subprojects are planned, the first based on social-network statistical methodology, the second based on autocatalytic dynamic modeling. The second of these subprojects has already been initiated, using Santa Fe Institute ‘seed money’ support.

(1) Marriage and family formation:

Philippa Pattison (University of Melbourne) is a renowned developer of social-network methodologies, both statistical and algebraic. Indeed in the specific subfield of concern to this project – namely, causal interaction among multiple social networks – she is the world pioneer. She will bring exploratory algebraic and exponential random graph modeling to bear on the statistical analysis of the Florentine data set.

Specifically in the domain of kinship and elite formation, Pattison and Padgett will statistically analyze the marriage and the patrilineage-descent networks conjointly, both in order to uncover aggregate network trends over time (in density, clustering, transitivity, characteristic path lengths, etc.) and in order to uncover the micro-structural (e.g., triadic) rules generating each time period’s marriage and descent networks. The substantive task of this statistical analysis is to discover the constraints that various elite structures (measured in marriage) and various family structures (measured in descent trees) impose on each other’s development and reproduction. This network-feedback topic is crucial for understanding the absorptive, the social mobility, and the ‘open elite’ capacities of various kinship systems – not just those of Renaissance Florence, but also those in contemporary developing countries.

This statistical exercise, comparing multiple time periods, is crucial empirical prelude for the subsequent modeling step of constructing a dynamic model of marriage and descent networks capable of tipping into different kinship ‘regimes’ in response to historically identified and analytically specified perturbations.

Model development will take place within a multiple network version of the family of exponential random graph distributions (Koehly and Pattison in press, Pattison and Wasserman 1999, 2002). These models treat multiple network ties as potentially interdependent random variables, and are built from an *a priori* specification of a *dependence* structure (Frank and Strauss 1986) for the multiple network. The dependence structure can be regarded as an hypothesis about the underlying topology of the multiple network: it specifies which pairs of network tie variables are conditionally dependent, given the values of all other tie variables. The Hammersley-Clifford theorem (Besag 1974) establishes that non-zero model parameters correspond to local *network neighborhoods*, that is to subsets of tie variables that are assumed to be mutually conditionally dependent. Since an hypothesized network topology may comprise many overlapping network neighborhoods, the approach leads to probabilistic models for multiple networks that are expressed as the outcome of self-organizing interactive processes occurring within overlapping local network regions.

Since this class of so-called p^* models was first introduced (Frank and Strauss 1986, Wasserman and Pattison 1996), several developments have extended their reach in ways that are likely to be important for the modeling exercise proposed here. Robins, Pattison and Elliott (2001) showed how to incorporate the interactions of node-level attributes with local network neighborhood effects, and hence how to understand the dependence of micro-structural network evolution rules on constellations of important

family characteristics. Pattison and Robins (2002) proposed a general approach for incorporating network effects that are dependent on the spatial or neighborhood distribution of nodes. Most importantly, Pattison and Robins (2002) introduced *realization-dependent* network topologies in which the conditional dependencies among tie variables are potentially dependent on the presence of other network ties. This development is important because it allows the construction of estimable models that have some of the properties of the autocatalytic models described in the section to follow. As a result, the models provide an important bridge between the rich Florentine data base and the dynamic network models that are one of the major goals of the project. Realisation-dependent models are also important because they often yield demonstrably better fits to data and hence possess better statistical properties (Snijders, Pattison, Robins and Handcock 2004). Since marriage and patrilineal-descent networks evolve in the context of highly visible local structures, realisation-dependent topologies are more than likely to be required.

The process of model development will be facilitated by the assessment of goodness-of-fit not just at the level of ties or local network structures, but also at the level of substantively significant global network properties (e.g., path length distribution, centralization, hierarchy). The assessment involves a comparison between features of the data and features of the distribution of multiple networks simulated from fitted model parameters (e.g., Snijders et al 2004). As Robins, Pattison and Woolcock (in press) have demonstrated, the relationship between parameter values and global network properties is not always intuitive; indeed, some parameter values yield “frozen” distributions in which highly regular structures of the kind associated with earlier algebraic accounts of multiple networks (e.g., Boorman and White 1976, Pattison 1993, White 1963) occur with high probability. This phenomenon explains why it is useful to allow exploratory algebraic approaches (e.g., Pattison and Wasserman 1996, Pattison, Wasserman, Robins and Kanfer 2000) to inform the initial specification of possible multiple network topologies.

(2) Marriage and faction formation:

Sanjay Jain (University of Delhi) is an Indian physicist, also on the external faculty of the Santa Fe Institute, who specializes in the dynamic modeling of autocatalytic networks in chemistry and biology. Among his other projects, he currently is writing a chapter for a volume on economic market formation edited by Padgett and Walter Powell (discussed below), which extends his existing autocatalytic models to the substantive domain of economic markets.

Jain and Padgett currently are collaborating in the development of a dynamic model of feedback between marriage networks and political-faction formation. With Jain’s graduate student, Varsha Kulkarni, they have already constructed a model of faction formation in the late-medieval period, when marriages were asymmetric (i.e., daughters flowing to different families than sons) and geographically contained. This model essentially superimposes a slow-time marriage-network topology on a fast-time tension-and-feud model of the propagation of political fights, and then examines how each shapes the other’s development over time. The base-level model of political feuding is a member of the ‘self-organized criticality’ class of models first developed by Per Bak (1988). Different size distributions of factions and fights are produced by different marriage network topologies, within the permissible class of late-medieval marriages.

The current model operates within a constrained set of marriage generation rules. The next step will be to allow evolution in marriage rules. For such evolution to occur endogenously the modeling framework will require the dynamic emergence of aggregates which lead to new correlations among existing nodes and new dimensions of attributional saliency. Such a feature is already present in rudimentary form in the work of Jain and Krishna (2001, 2002a, b). In their model of evolution of an autocatalytic network in a prebiotic pond, when a small autocatalytic set initially appears, it is enough for incoming molecular species to have catalytic links with any member of this set in order to achieve high populations and hence stability against fluctuations. But in due course the autocatalytic set acquires a structure consisting of a nested core surrounded by a parasitic periphery, and the population success of the nodes comes to depend upon how close they are to the core. The effective rules for the successful survival of a node within the larger organization therefore endogenously evolve as a new aggregate (the core) dynamically forms in the system.

This framework will have to be enriched – in particular to allow feedback among multiple networks – in order to model the evolution of marriage rules in Florence, and to see if and when a transition to ‘Renaissance style’ elites-with-political-clientage occurs. But an example of the phenomena that the autocatalytic framework may well help to illuminate is the 1290s transition of symmetric medieval factions into asymmetric ‘magnates vs. popolani’ with the addition of guild-based partnership links by one of the elite factions to new men. In this case, magnate families reverted into even more solidaristic *consorterie*, whereas popolani families opened out in marriage into almost classless exogamy, thereby sending the kinship system down a new road of evolution.

V. The Economic Development of International Finance, Credit and Markets

A. Past Empirical Findings

Florence was wealthy (a) because in the early fourteenth century it developed a wool-textile industry that displaced Flanders as the lead city in Europe for one century, (b) because in the early fifteenth century it developed a silk-textile industry that was among the European centers for two centuries, but most of all (c) because throughout the fourteen and fifteenth centuries it developed and dominated international finance throughout Europe. These three industries were not independent. All three were developed by Florentine merchant-bankers – a class of ‘generalist’ businessmen who combined merchant trading and distribution with the provision of banking, exchange, and credit services to their customers (businessmen, clerics and nobles all over Europe). Understanding organizational innovation in the economic domain means understanding how the Florentine merchant-bankers worked.

Using their data, Padgett and McLean have published extensively on this subject. Two specific topics have been studied intensively: (a) transformation in the partnership structure of Florentine banks, over time (Padgett 2001, forthcoming; see also de Roover 1966, Melis 1991) and (b) the network structure of Florentine credit, across all industries, in 1427 (Padgett and McLean 1997, 2004, forthcoming). The financial innovations of concern in these studies are the emergence of the ‘holding company’ form of linked limited-liability partnerships, and the emergence and diffusion of current accounts in double-entry bookkeeping. Both of these organizational innovations, which made capital more liquid, occurred in the late fourteenth century, soon after the Ciompi political revolt.

Before that time, partnership structure and economic credit were grounded in patrilineage and guild. While viable these were more constrained in scale and scope.

Unlike previous economic historians, Padgett and McLean had the systematic data to examine these economic transformations in the contexts of the kinship and political, as well as the economic and institutional, networks of the merchant-bankers who produced them. They found that these particular economic innovations were produced by, or at least were highly correlated with, the political transformation in social elite structure discussed in the previous section. Specifically, economic transformation in organizational form from unitary patrilineage firm to overlapping, linked partnerships was paralleled by the social refocus in kinship from descent to marriage. Partnerships were socially embedded in marriage (an estimated 20% of partners were intermarried at the level of their nuclear families), and the contract of partnership was a generalization of the previous legal model of marriage with dowry. Similarly, economic transformation in credit from transactional loans to open-ended, relational current accounts was paralleled by the post-Ciampi destruction of guilds and the emergence of patron-clientage as a political substitute. Neighborhood became the social framework and backdrop to current accounts: even when Florentines lived and worked far from home, they sought out natal neighbors as the businessmen with whom they extended open-ended credit. Padgett and McLean (forthcoming) give many quotations from the business correspondence of the time that emphasize that ‘making friends’ and ‘making profits’ were virtually the same concept to the Florentine mind. McLean (1998) further demonstrates that the Italian words *amicizia* (friendship) and *utile* (profit) co-occur with high statistical frequency in Renaissance Florentine correspondence.

Following biological terminology, we call such transpositions of social logics or models from one domain to another ‘refunctionality’. Such transpositions – seeing old ideas or practices in a new light or purpose – we believe are the micro-mechanisms underlying much human (as well as biological) innovation. Probably individual-level transpositions occur with some frequency as background ‘noise’ in any society. But rarely do these cascade into systemic transformation. System dynamics depend upon how the reproduction of multiple networks – economic, political and social – intercalate.

While details will differ from place to place, such empirical findings offer the promise of application and insight to a wide array of cases of organizational innovation. But for this to happen, tools that generalize these empirical discoveries need to be built.

B. *Current and Future Modeling Projects*

(1) Credit and Brokerage:

Pattison, Padgett and McLean have started analyzing the 1427 *catasto* credit data with p* statistical methodology, developed for social-network analysis by Pattison and Wasserman (1996, 1999). Padgett and McLean (forthcoming) had analyzed these data through logit regression as a set of dyads, without fully taking into account the triadic and higher interdependencies that no doubt existed in the data. p* is designed explicitly to deal with the indirect causal interactions so common in network analysis, which violate independence assumptions built into traditional estimation procedures. Substantively, this is a study of brokerage: the effect of third parties on likelihood of credit between others. This statistical subproject, therefore, builds on the first-order ‘social context’ findings in Padgett and McLean (forthcoming) to search for second-order ‘catalytic’ effects that propagate credit-formation in one part of the economic-market network into credit-

formation in other parts of that network. Nonlinearities in the dynamics of market formation hinge on such brokerage or ‘catalysis’ effects. Qualitative historical research gives much reason to suspect the ‘open elite’ of merchant-bankers who were also part-time political office-holders being at the generative network center of the Florentines’ remarkable capacity to produce and extend (yet also to police) credit and liquidity.

(2) Hypercycles of Skills and Careers in Economic Firm Formation:

Inspired by Eigen and Schuster’s Nobel-prize winning work (1979) on the ‘hypercycle’ origins of self-reproducing chemical metabolism (i.e., ‘life’), Padgett, Lee and Collier (1997b, 2003) have adapted that modeling framework to the setting of economic production in an agent-based simulation. The model started with this premise: “The production and distribution of goods by firms are only half of what is accomplished in markets. Firms also are produced and transformed through goods passing through them.” (ibid., p. 843) It posited various sets of potentially interlinked rules or skills; it specified various learning mechanisms for the reproduction of those rules; and it then explored various social-interactional principles that affected the self-organization of such rule sets into reproducing technologies and spatial ecologies of trading firms. “What the article has done is to establish three principles of social organization that provide sufficient foundations for the unconscious evolution of technological complexity: structured topology, altruistic learning, and stigmergy.” (p.865) [‘Stigmergy’, a concept from the social-insect literature, is feedback between physical and social structure.]

There is considerable distance between the minimalist austerity of the hypercycle model and the historical complexity of Renaissance Florence. However, one step toward closing the gap would be to construct a somewhat generic ‘hypercycle model of industrial districts’ by adding career flows of people between firms (rule diffusion) and firm genealogies (mergers and spinoffs) to the existing framework. ‘Firm-formation regimes’ would be different chemistries of partner attraction and reproduction, and ‘market network topology’ would be credit links between firms. This extension would move the model closer to the Florentine annual-time-series data on bank partnerships, and would implement diagrammatic suggestions about firm-career duality found in Padgett (2001, p. 227-229). Testable model predictions would be firm-size distributions, career chains, and volatility in rates of firm formation and dissolution.

This extension also would move the model closer to possible application to other examples of industrial districts, such as Silicon Valley. Doowan Lee, the graduate-student coauthor of the hypercycle model, will take the lead in implementing this subproject.

(3) Transposition and Catalysis in Social Networks:

The greatest analytical challenge will be modeling refunctionality. We are aware of no existing model in the dynamical-systems, the social-network, or the agent-based modeling families that takes seriously the endogenous content of network ties. McLean’s dissertation (1996) provided rich linguistic and cultural detail from recommendation letters on the micro-processes of Florentines negotiating their political relationships. Padgett and McLean (forthcoming) provide similar examples from Florentine business letters. Such ethnographic work lays the empirical foundation for our collective attempt to model refunctionality at the more mezzo level of social-network dynamics.

In view of the novelty and difficulty of this exploratory modeling venture, no one or two people will be in charge. Pooling their multiple skills, this will be a collective effort by the entire research team, joined also by SFI research professor Walter Fontana,

an expert on computation and computational chemistry who has a deep interest in computational linguistics. To avoid overreaching, we plan to begin by sticking closely to the Florentine materials through the construction of an agent-based simulation of the Ciompi revolt – that historical moment in Florentine history when refunctionality-style economic innovations were most prominent and obvious. Tipping in politics, tipping in markets, and tipping in kinship all co-evolved in this dramatic ‘punctuated equilibrium’ moment in Florentine history. To succeed in reproducing such dynamic behavior in an agent-based model will require a careful and historically accurate reconstruction of the prior patrilineage-guild regime. David Sallach and his programming staff at Argonne will aid in implementing the projected agent-based model in Repast.

VI. Political Parties, Clientage and Republicanism

A. Past Empirical Findings

Padgett and Ansell (1993), in their “Robust Action and the Rise of the Medici, 1400-1434,” analyzed the network structure of the political party that Cosimo de’ Medici used to take power and centralize the state in 1434. Their core methodology was blockmodel analysis (White, Boorman and Breiger 1976) of a sample of the marriage, business, and friendship ties within the Florentine elite of that time. Supplementary textual and statistical information was mobilized to explain how this political party structure emerged, over a thirty year period. The main finding was that Medici centralization emerged from stapling together contradictory subsets of multiple networks through robust action. “Class revolt and fiscal crisis were the ultimate causes of elite consolidation, but Medicean political control was produced by means of network disjunctures within the elite, which the Medici alone spanned. Cosimo de’ Medici’s multivocal identity as sphinx harnessed the power available in these network holes and resolved the contradiction between judge and boss inherent in all organizations. We argue that to understand state formation one must penetrate beneath the veneer of formal institutions, groups and goals down to the relational substrata of people’s actual lives. Ambiguity and heterogeneity, not planning and self-interest, are the raw materials of which powerful states and persons are constructed.” (ibid, p. 1259)

The ‘contradictory subsets of multiple networks’ in question were (a) marriage ties to disaffected Ricci-faction patricians, excluded from power due to their past support of the Ciompi, and (b) economic ties of credit and partnership to new-men neighbors-cum-clients of the Medici. The political party itself, in other words, was constructed through cross-cutting kinship with economic markets. Florentine state formation was rooted in, indeed was a recombination of, prior developments in those other network areas. This is what we mean by ‘multiple network feedback’ in the political domain.

B. Current and Future Modeling Projects

(1) Other episodes of political-faction formation:

Padgett has spent much time since that AJS article collecting the data necessary to redo his blockmodeling exercise for other faction-formation periods in Florentine political history – magnates vs. popolani in the 1290s, Black vs. White Guelfs in the 1310s, Albizzi vs. Ricci in the 1360s, Ciompi revolt in 1378, anti-Medici republican reaction in 1466, and the Savonarola revolt in the 1490s. Historically, these can be clustered in pairs and analyzed as three temporally extended episodes. Given the time, Padgett and McLean, with graduate-student assistants, will carry out these

methodologically straightforward but data intensive studies. Pattison, an early contributor to the development of blockmodel analysis, will act as statistical consultant.

(2) Modeling Republicanism:

Untouched in Padgett's prior empirical research is the formal institutional side of republicanism – the participatory structure of state offices, eligibility, and elections (Najemy 1982). The historical significance of this for political theory is obvious. Yet the causal importance of this for the development and regulation of political and other networks is also clear: On the one hand, the outcome of factional struggle was always in part the 'reform' of such institutional rules; on the other, the structure of political offices affected the social demography of elite control and status mobility, and thereby the shape of political discontent and revolt. This lacuna needs to be addressed in future research.

A three-pronged research strategy is envisioned:

(a) Logit analyses of entry into various political offices, comparing different political regimes, will trace the social and political consequences of different constitutional rules. In collaboration with University of Chicago political science graduate student Michael Heaney, Padgett has already carried out some of these statistical analyses, which reveal dramatic changes across political regimes. These analyses have yet to be published.

(b) An agent-based organizational demography model will be built combining institutional structure, political careers, and (changing) clientage voting. A strong sociological modeling tradition exists in organizational demography (White 1970, Bartholomew 1982, Stewman 1983, 1988). This has already been partially adapted to the Florentine case in a Santa Fe Institute working paper (Padgett 2000). Sallach and his Argonne programming staff will build an agent-based model of career flows within and across Florentine political offices and economic firms, fitted with real data. This model will calculate rates of political mobility and social intermixing, linking economics, kinship and politics into different biographical life-courses for various political regimes. Both this organizational demography model and the hypercyclic partnership-formation model discussed in V.B(2) may turn into components of the more synthetic Ciompi-revolt refunctionality model discussed in V.B(3).

(c) Textual analysis of contemporaneous political constitutional debates. Next year Padgett will co-teach a University of Chicago course on Florentine republicanism with John McCormick, a tenured political theorist recently recruited from Yale. McLean also has linguistic proficiency and a background in Machiavelli. As the course develops, Padgett hopes that a collaboration will develop among these three that examines side-by-side the statistical analyses above with contemporaneous constitutional debates, both among politicians (in *consulte e pratiche* councils) and among humanists. Such a juxtaposition between statistics and texts would be novel in intellectual history, possibly generating new leads on the persistent challenge of how to link network analysis with cultural analysis (Emirbayer and Goodwin 1994). This exercise will be of interest to historians not otherwise interested in modeling. For example, given his interests and Latin skills, Samuel Cohn, the distinguished Florentine historian at the University of Glasgow with whom Padgett has worked in the archives, may also join this venture.

VII. Relevance of Project to Collateral Areas of Application

While this project proposal centers specifically on analyzing and modeling the Florentine data set, it fits with the collateral comparative and methodological research objectives of the principals in the following ways:

(a) With Walter Powell, Padgett has a grant from the Hewlett foundation, ending in 2006, which funds SFI conferences and working groups that bring together and compare a number of empirical examples of dynamic market formation – U.S. biotechnology (Powell), Silicon Valley engineering (Fleming), twentieth century Broadway musicals (Uzzi), post-Communist Russian bankers-cum-oligarchs (Spicer and Kogut), post-Communist Hungarian privatization (Stark), Renaissance Italian banking (Padgett), and the seventeenth century London stock market (Carruthers). A MIT-press book produced by this working group and edited by Padgett and Powell is currently in preparation, scheduled for completion in summer of 2004. Both Padgett's Florence project and Powell's biotechnology project involve the construction and analysis of comprehensive dynamic-network data sets. Intensive feedback at many levels, for one month each year, has been fostered by this SFI-Hewlett mechanism. This NSF-HSD proposal requests funding for intensive analysis of the Florentine case. The Hewlett grant funds comparison of that case with a broad array of other market formation episodes.

(b) Pattison will use the Florentine data to illustrate and to support her methodological objectives in the development of models for social network structures, network evolution, and the co-evolution of interdependent social processes at multiple levels of analysis (e.g., individuals, families and firms). Her work on the Florentine data will complement a general methodological project supported by a grant from the Australian Research Council to Pattison, Robins (Melbourne) and Snijders (Groningen).

(c) Jain will use the Florentine data to illustrate and support his methodological objectives in the dynamic modeling of autocatalytic networks. For example, the coevolution of multiple networks, refunctionality, and the emergence of new dimensions of attributional saliency are important themes for network dynamics in other fields as well, such as evolutionary biology and prebiotic chemistry. Jain is interested in the origin of life problem, in which one of the major puzzles is how several distinct but overlapping networks, such as the metabolic network, the regulatory network, and the protein interaction network, emerged and coevolved. Models of coevolution of the economic and political networks in Florence will provide useful insight at the abstract level of how the dynamics of one network can influence the formation of structure in another. Modeling discontinuous transitions in Renaissance Florence also will enrich Jain's earlier abstract modeling describing 'core shifts', crashes and recoveries in evolving networks with concrete data as well as newer mathematical concepts.

(d) Sallach will use the Florentine data to illustrate and support his methodological objectives in agent-based simulation. The empirical networks that will parameterize the model are complex, sometimes fragmentary, and always intertwined. Moreover, they imply constraints on behavior that typically are observed, but sometimes are challenged by the historical actors who participated in these relationships. They also provided opportunities and affordances that became the basis for the refunctionality that characterizes the transition from one structural era to another. Through this project, all these features will be added to the next generation of Java-based and open-source Repast.

(e) McLean will use the Florentine data to advance his goals in linguistic and textual analysis. He is currently at work on a book manuscript entitled *The Art of the*

Network: Strategic Interaction and Patronage in Renaissance Florence. The book examines how the writers of Florentine patronage letters actively constructed their social networks and engaged in credible self-presentation through improvisational assembly of a host of stock discursive techniques and cognitive frames. Such techniques and frames appear with marked regularity in hundreds, if not thousands, of fifteenth century Florentine letters. Thus there is a good deal of cultural work in social network construction; networks are constituted and maintained interactionally. The book will provide sociologists of culture with a fresh toolbox of concepts derived from discourse analysis, and give comparative historians a fresh perspective on the co-evolution of state institutions and interpersonal interaction styles (cf. Elias 1978).

A unique feature of this proposal is the application of three distinct complex-systems modeling approaches to the problem of understanding organizational innovation in Renaissance Florence. As already indicated, the applications are made in the context of an extraordinarily rich data set that provides essential opportunities for empirical calibration. Although not emphasized above, there are two important likely methodological consequences of the proposed work. The first is a significant level of innovation in the modeling approaches themselves because of the strong empirical tests to which they will be put. The second is a significant potential for cross-fertilization among the three approaches. For instance, improved understanding of network topologies should lead to more realistic autocatalytic and agent-based models, and an understanding of the properties of dynamic models that account for major qualitative features of organizational innovation should lead to more appropriate specifications of network-based statistical models. The results of such methodological cross-talk should have broad impact beyond the context of the proposed project.

VIII. Project Schedule

Anticipated work schedules of the senior scientists are given below. Each of these scientists will be working with junior assistants, not identified here. Padgett is involved in all of these subprojects, and so is not allocated specifically.

<i>Kinship:</i>	<u>Year 1</u>	<u>Year 2</u>	<u>Year 3</u>
Marriage and family formation	Pattison	Pattison	[done]
Marriage and faction model	Jain	Jain	[done]
<i>Economics:</i>			
Credit and brokerage	Pattison	[done]	
Hypercycles of firm formation	Lee	Lee	[done]
Refunctionality in Ciompi revolt	---	everyone	everyone
<i>Politics:</i>			(esp. Sallach)
Blockmodeling of faction formation	McLean	McLean	McLean
Regressions of political officeholding	Padgett	[done]	
Organizational demography model	Sallach	Sallach	[done]
Political debates	---	McCormick	McCormick
		(and McLean and Cohn?)	

This research team will be assembled for one month each summer at the Santa Fe Institute, to induce and ensure collaboration and deep interdisciplinary exchange. (Powell will also be there, on the Hewlett grant.) Specific travel outside this month will also be funded, on a need basis. Thus the intellectual and work-load boundaries between these subprojects are far more porous than this 'management plan' makes them appear.

IX. Educational Outreach

Due to his commitment to the apprenticeship model of research training of graduate students, Padgett during his four years of affiliation as a SFI research-professor has brought through SFI a considerable stream of University of Chicago graduate students: Hugh Rhodes (African-American), Doowan Lee (Korean), Michael Heaney, Elena Obukova (Russian), Frank Smith, and Matteo Colombi (Italian). This year Xing Zhong (Chinese) will take her turn in this sequence. At SFI, Padgett has worked with these students directly as chair of their dissertations, has sponsored them through the SFI summer schools, and has involved them as active participants in daily work-group seminars. In addition, the undergraduate apprentice program of SFI brought one social-network-oriented undergraduate (Skye Bendor-deMoll) from Bennington to Padgett, whom Padgett subsequently brought back to Chicago. Through the Hewlett grant, Walter Powell sponsored a similar stream of diverse students from Stanford. Such student flows, in our opinion, are crucial not only for the success of research projects, but also for the institutional vitality of the Santa Fe Institute, and for the interdisciplinary breadth such exposure brings to the students.

This past successful training and collaboration activity will continue during this grant, as a matter of course, this time building new streams of incoming students from the universities of Melbourne, Delhi and Rutgers.

The SFI-Argonne connection, built through Padgett, already has produced unanticipated educational spinoffs. Michael North, an agent-based modeler at Argonne who works closely with Sallach, has taken the lead in organizing SFI and Argonne personnel into giving an annual week-long training program to American businesses associated with the Santa Fe Institute's business network. Padgett has taught in this, as has Sallach. Participating businesses have found these agent-based training programs to be among the most significant of the benefits they receive from their affiliation with SFI.

Padgett also currently is deeply involved in negotiations with three Italian universities to build and to co-sponsor a European Santa Fe Institute summer school. This school will parallel the educational outreach that SFI already does in Santa Fe, New Mexico and in China. While this entrepreneurial activity has nothing to do with this grant proposal per se, it typifies the spirit with which SFI approaches its educational mission. Sanjay Jain is exploring the prospects for a similar such school in India.

X. Diversity

The international and ethnically diverse flavor of this research team is obvious. Senior scientists are from Australia and India, as well as America. Currently involved graduate students are from India, Korea, China and Italy, no doubt with more to come in the future. (For example, Padgett is evaluating a U of C graduate student from Mexico for possible future inclusion.) Female representation, while not 50-50, is substantial. In part the international orientation of this research team stems from Padgett's personal preferences, since his research on Italy naturally inclines him in that direction. But more important is the fact that science itself has become international. These simply are the most qualified people in the world for these tasks. One of the powerful assets the Santa Fe Institute possesses is its strong international orientation. Science in every country, including America, benefits from the intellectual as well as the national diversity that places like SFI promote.