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Circular autopoiesis dynamics in virtual enterprise networks

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Abstract—Although still flying low under the popular business media's collective radar, virtual enterprise networks (or nets) do receive increased attention in the strategic management literature. A virtual enterprise network (VEN) is a system of autonomous firms that collaborate to achieve common business objectives. VENs give participants a competitive edge in markets demanding agility and rapid response. Seen as an emerging transactional exchange governance (TEG) form within transaction cost economics (TCE), VENs and the relations among firms that form them posit challenges for researchers and managers. VENs differ substantially from markets and hierarchies, and from recurrent and relational contracts, utterly changing what it means to be a firm in today's business. This essay explores alternative TEG forms, their characteristics and the criteria that bear on the choice of corporate governance: flexible specialization, market uncertainty, product (good or service) complexity, reliance on trust, risk, self-organization, shared knowledge, and socio-territorial cohesiveness. The essay offers propositions on the relations among economic criteria and the choice of transactional exchange governance forms by exploring the dynamics of a generic TEG structure. This is a system dynamics simulation model that partially offsets the shortcomings of transaction cost economics (TCE) and points to the potentially rich contribution of system dynamics to exploring VENs beyond the ideal-type TEG forms of markets and hierarchies that dominate the TCE literature.

Keywords: autopoiesis, strategy, system dynamics, transaction cost economics, virtual enterprise networks

1. Introduction

Ahuja & Carley (1998) define a VEN as a geographically distributed organization whose members, bound by a long-term common interest or goal, communicate and coordinate their work through information & communication technology (ICT). Grabowski et al (1998) add that VENs' multiple, distributed members are temporarily linked together for competitive advantage, produce and share value chains (Zeleny 1999a) and business processes (Peppard 1999) supported by distributed ICT (Anon. 1993, Davidow & Malone 1992). In discussing new forms of organization enabled by ICT, Drucker (1988) suggests that VENs might be most evident in research and development (R&D). Although VENs draw on research on network organizations (Jarillo 1988, Nohria & Eccles 1992, Powell 1990, Thorelli 1986), inter-organizational systems (Barrett & Konsynski 1982, Johnston & Vitale 1988, Konsynski 1990) and virtual organizations (Davidow & Malone 1992, Goldman, Nagel & Preiss 1995, Preiss, Goldman & Nagel 1996), the VEN literature is still in its infancy.

Indeed, after decades of research, VENs, such as market-centric small and medium enterprise (SME) networks are still poorly understood, despite their driving economic growth from the industrial districts (IDs) of Italy to the entrepreneurial cluster of American Silicon Valley, Bavarian Isar Valley, Norwegian Nordvest Forum, plus a large number of VENs in other regions, from Australia to China to Spain. Being self-organizing systems, VENs drive jobs, disinflation and productivity on a global scale. Yet, they are still enigmatic with respect to what lies at the core of their success; the theory behind VENs and SMEs is absent (Zeleny 1999b).

What makes firms—virtual or real and small or large—succeed or fail has preoccupied the strategy field since its inception. The reason why firms succeed or fail is inextricably bound up in questions such as: why firms differ, how they behave, how they design strategy and how they run themselves. Yet, despite the considerable progress in developing static models of competitive success, far less developed is our understanding of the dynamic processes by which firms attain superior performance (Porter 1991). Traditional economic models of strategy embody crucial assumptions about the nature of firms and their environment. The rationality assumption, for example, used to be the defining characteristic of economics (Lucas 1986). During the last twenty years, however, at least five *monkey wrenches* have been thrown into the economist's neoclassical model of the firm. They are: uncertainty, information asymmetry, bounded rationality, opportunism and asset specificity. These violate the neoclassical portrayal of the firm—a smoothly running machine in a world without secrets, uncertainty or a temporal dimension (Rumelt, Schendel & Teece 1991).

Proponents of the cross-sectional view of strategy often frame the determinants of superior performance as a static chain of causality. They assume that the dynamic processes pertinent to creating competitive positions are logically posterior to such a chain. So, the argument goes, to understand the dynamics of strategy, one must move further back in the static chain of causality. This static perspective highlights the managerial choices behind initial conditions internal to firms, distinctive competencies (Selznick 1957) and competitive positions, which result from decisions that entail hard-to-reverse commitments (Ghemawat 1991). Ghemawat posits that analyzing such decisions should begin with cross-sectional models but, in choosing competitive positions, he stresses the need to examine their sustainability over time as well as the effect of uncertainty on chosen investments. Changes in the environment, for example, in technology and in strategy prompt firms to seek sustainable cooperative relationships with each other.

This view of sustainability is broader than what is generally present in, say, game theory models. Brams' (1993) essay is one exception in game theory that considers outcome sustainability. Sustainability is relevant to all systems in and about which we live and work. Its proximity to scenario-driven planning allows assessing resource investment decisions from a strategic perspective, while at once managing strategic uncertainty to create informational asymmetries, i.e., good managerial choices (Georgantzas & Acar 1995, Schoemaker 1993).

Taking the role of a generic TEG (transactional exchange governance) structure, a system dynamics model helps examine how changes in the business environment of firms that form VENs may affect their success or failure, success being their sustainable profitability. The model incorporates policy parameters of organizational innovation and internal control costs, which affect VENs' autopoiesis (self-production). Additionally, the model incorporates ideas from the transaction cost economics (TCE) branch of organizational economics (Williamson 1975, Williamson 1985), particularly its internalization theory extensions, which explore the effects of internal costs of control on TEG choices (Hill & Kim 1988, Kogut 1988, Teece 1982).

The following section gives a brief account of the merger and acquisition (M&A) and TCE content literature. Subsequently, an overview of VEN characteristics and the poiesis-bonding-degradation process (Zeleny 1999b) precedes the system dynamics simulation model description. It is perhaps their capacity to reintegrate the content and process perspectives of strategy that has turn system dynamics into a new paradigm for competitive advantage (Istvan 1992) and simulation modeling in general into a critical fifth tool in addition to the four tools used in science: observation, logical/mathematical analysis, hypothesis testing and experiment (Turner 1997).

Yet, system dynamics simulation models also allow computing scenarios to assess the possible implications of strategic situations. These are not merely hypothesized plausible futures, but computed by simulating changes in the competitive environment. Following a description of model structure, computed scenarios assess the sensitivity of the generic TEG structure. The simulation results show the dynamic evolution of TEG forms that might create alternative futures for VENs. The results also point to the potentially rich contribution of system dynamics to exploring VENs beyond the ideal-type TEG forms of markets and hierarchies that dominate the TCE literature.

2. TCE: conceptual underpinnings

Porter's (1985) value-chain framework decomposes firms and industries into distinct activities, while TCE makes the specific type of repeated activity the unit of analysis. MacMillan & Farmer (1979) distinguish between supplier charges and cost to the buyer, including transaction costs. Firms will integrate an activity if the external supplier charges plus the transaction costs exceed the internalization cost. If, however, a firm lowers transaction costs down to a point where the internalization cost exceeds supplier charges plus transaction costs, then, to remain competitive, the firm will not integrate the activity. This is a powerful rationale behind IDs, M&As, SMEs, VENs and other TEG forms in any industry.

The relatedness hypothesis suggests that bonds among related firms would generate higher returns than bonds among unrelated firms. M&A empirical evidence supports this hypothesis for target firms (Singh & Montgomery 1987), but has been mixed for acquiring firms (Chatterjee 1986, Lubatkin 1983). Acquiring firms may enjoy abnormal returns only in the presence of private, inimitable or unexpected and uniquely related cash flows with target firms (Barney 1988, Lippman & Rumelt 1982).

Firms are related when the net present value (NPV) of the cash flow of their merger is greater than the sum of the NPVs of the cash flows of the firms acting independently (Copeland & Weston 1983). Among the multiple sources of M&A relatedness cited, Lubatkin (1983) has grouped nine types of relatedness between acquiring and target firms into three categories: technical economies (i.e., marketing and production economies); pecuniary economies (i.e., market power); and portfolio economies (i.e., risk reduction). Relatedness among firms can reflect any one or a combination of these sources. With cash flow net of any transaction costs, the price *acquiring* firms would pay would not depend on the value of *target* firms acting independently, but on the value target firms create when they join the acquiring firms' value chain (or VEN). If acquiring and target firms are unrelated, then the targets' cash flow NPVs set the price (Barney 1988, Copeland & Weston 1983).

Indeed, mergers and acquisitions represent expeditious ways to keeping pace with change, particularly when firms seek new assets and competencies (Barney 1988, Lippman & Rumelt 1982, Singh & Montgomery 1987). Alternatively, pursuing cooperation because of reciprocal dependencies may cause firms to opt for contract-based governance. The transactional exchange governance forms that firms use because of reciprocal dependencies include strategic alliances, partnerships, coalitions, franchises, research consortia and virtual enterprise network organizations (Jarillo 1988, Powell 1990, Ring & Van de Ven 1992).

Egressing from Williamson's (1991) extension of Coase's transaction cost analysis of the firm, economists have formed a branch of organizational economics now known as transaction cost economics (TCE). Ronald Coase (1952) was the first to give a lucid explanation of transaction costs, a discovery so important that he was awarded a Nobel Prize 50 years later. Coase recognized that markets often deviate from the neoclassical ideal, creating impediments to market exchange. Monopoly, uncertainty or difficulties in price determination cause market failure. Firms are created because their additional cost of organizing is still less than the transaction costs involved when individuals conduct business with each other. TEG payoff stems from overcoming impediments to market exchange, including the transaction costs of (a) drafting, negotiating, monitoring and enforcing comprehensive claims contracts, and (b) firm-specific knowledge dissemination attributed to opportunism by external contractors. Coase concluded that firms must conduct internally only those activities that cannot be performed more cheaply in the market or by another firm. Firms must expand precisely to the point where the cost of organizing an extra transaction within becomes equal to the cost of carrying out the same transaction by means of a sovereign market exchange.

TCE rests on the conjunction of bounded rationality (Simon 1957), asset specificity and opportunism. It explores governance options, such as discrete market contracts, recurrent contracts, network organizations, relational contracts and hierarchies (Jarillo 1988, Lippman & Rumelt 1982, MacMillan & Farmer 1979, Powell 1990, Ring & Van de Ven 1992). Although TCE operates on the assumption that economy is the best strategy, this does not mean that strategies that distribute risk and deter rivals with clever tactics and postures are unimportant. In the long run, however, the best option is to design efficient strategy efficiently and to implement it efficiently (Williamson 1991). Williamson contends that if strategic management is to unlock the sources of long-term competitive advantage, and if is going to rely on economic thinking, then it ought not to rely so uncritically on perspectives that appeal to market power but restrict product competition as the source of competitive advantage. Rather, the field should develop more of an efficiency perspective: being good at what firms do and avoiding waste is more important than exploiting switching costs or playing oligopoly games.

Porter (1991) finds the connection between resources and activities fundamental because resources represent an inherently intermediate position in the cross-sectional view of the chain of causality. Resources arise either from performing activities, acquiring them from outside, or some combination of the two. Both reflect prior managerial choices. Performing an activity or group of linked activities over time creates competencies and routines that accumulate. It also can create external assets. A firm’s reputation, for example, could be a function of the history of its marketing and customer service activities. Assets and technology depreciate, however, unless reinvigorated though organizational, i.e., technological (or technical) and administrative, innovation (Georgantzas & Shapiro 1993). Depreciation varies widely across different assets and technology, but can be rapid. Firms accumulate differing resources because of differing strategies and configuration of activities. Resources and activities are, in a sense, dual of each other.

It is worth noting that Porter’s low-cost producer differs from Williamson’s economizing firm. The economizer is not necessarily efficient at production, but in a broad range of business functions. For example, the economizer may be very efficient at managing the transition from design to production, or at tailoring products to local tastes. Williamson’s position on this issue is at variance with the traditional (economic) assumption that firms are ’on their cost curves.’ If firms are assumed to be technically efficient, the problem is simply to determine the level of output. In stark contrast, Williamson sees the fundamental challenge as one of organizing and governing all activities to eliminate waste.

TCE extensions view TEG forms as a hierarchical response to market imperfections, positing that it is more economical for firms to overcome impediments to market exchange by establishing internal markets than to incur the prohibitive transaction costs of the external one. Among subfields of economics, TCE has the greatest affinity with strategy, partly because of a common interest in governance forms, including the Chandler-Williamson M-form hypothesis that entails multi-divisional or multi-product firms, and the shared concern to legitimize inquiry into institutional details. Within strategic management, Rumelt et al (1991) find in TCE the ground where economic thinking, strategy and organization theory meet. Indeed, considerable research was carried out in the 1980s on vertical supply arrangements in industries (Masten 1988, Monteverde & Teece 1982), multinational firms (Hill & Kim 1988, Kogut 1988, Teece 1983), sales force organization (Anderson & Schmittlein 1984), joint ventures (Hennart 1988, Pisano 1990) and franchising (Klein 1980).

The above arguments support using TCE in evaluating alternative transactional exchange governance forms to explore strategic dependencies among firms. Yet, TCE suffers from several weaknesses. Excluding the internationalization model of Hill & Kim (1988), TCE analysis is static (Ring & Van de Ven 1992), paying a little attention to the dynamic effects of internal cost of control on governance choices. Also, by focusing on the transaction cost implications of different TEG modes, TCE research overlooks the effects of each on revenue and profitability (Contractor 1984, Teece 1983). Lastly, in highly uncertain or risky situations, if reliance on trust is possible, it is conceivable that hierarchies will begin to look like clans and networks of contracts (Ring & Van de Ven 1992, Stinchcombe 1990).

Consistent with the idea of partitioning complex problems for system dynamics modeling (Morecroft 1985, Saeed 1992), the generic TEG structure described here, adapted from Georgantzas et al (1994), partially overcomes these flaws. To attain clarity of presentation and to save space, the model concentrates on VENs, although the issues surrounding other TEG forms that create internal markets, i.e., M&As and joint ventures, are implicit in the structure's framework. The model posits technological innovation, administrative innovation and internal control costs as the primary determinants of VENs. The simulation output resulting from the model's structure shows VENs' sensitivity to policy parameters, such as learning rate, relatedness and bonding time.

3. VENs: children of TEG

In the early 20th century, Henry Ford built a large traditional hierarchy through typical employment contracts, which achieved superlative *vertical integration*: in came iron ore and rubber, out came automobiles driven by customers. Ford made its own steel, tires and parts, then assembled them into cars. Although a few firms ever achieve such self-sufficiency, the vertical integration ideal would lead business strategy throughout the century. The desire to control everything pushed firms to do everything for themselves. They reluctantly used others either for parts or for reaching customers.

Today, backward and forward vertical integration remains a transactional exchange governance (TEG) option for managers who find it hard to part with the belligerent attitudes of competitive strategy. It is a costly alternative, however, because it requires internalizing all transactions in a firm's industry value chain through backward and forward integration. The resulting vast traditional hierarchy must develop the ability to produce the goods and services it previously purchased or actually buy all its suppliers and distributors up and down the industry value chain.

And in today's hypercompetitive environment, a firm must be the best at everything it does. Is it possible, however, in an ever more adaptively complex, self-organizing world, for any one huge traditional hierarchy (a dinosaur of sorts) to be tops at everything it does?

Virtual—as opposed to vertical—integration is the natural solution. A VEN enables its participants to concentrate on processes at which they are world-class and to rely on other VEN members for the rest. And ICT allows coordinating all their processes *virtually* as one firm.

Although mergers and acquisitions represent expeditious ways to keeping pace with change, particularly when firms seek new assets and competencies (Barney 1988), pursuing cooperation because of reciprocal dependencies may cause firms to opt for contract-based governance or VENs. The contract-based governance forms that firms use because of reciprocal dependencies include strategic alliances, partnerships, coalitions, franchises, research consortia and network organizations (Ring & Van de Ven 1992). Inspired by the work of Barney and Ring & Van de Ven, Fig. 1 and Table 1 show the characteristic dimensions of five TEG forms, making VENs the fifth element of transactional exchange governance (TEG).

Qualified VEN members, i.e., firms internally run as autopoietic networks, share strategic objectives, drive down lead time efficiently, minimize total inventory cost, maximize equipment utilization, and design goods and services that maximize performance and minimize cost. To be both effective and efficient, VEN members must ensure that their selected business strategy becomes integrated both backward and forward in their net's value chain. This is an achievement because a VEN's value chain is the entire industry value chain, fifth- and sixth-tier suppliers and end-user customers included.

Cisco Systems is a good VEN-member example. Cisco concentrates on two essential processes—developing new products and selling products to customers—and leaves the rest to other VEN members. An autonomous manufacturer assembles Cisco's products from parts made by independent suppliers. An autonomous materials-management firm ensures the right amount of inventory is on hand and delivers assembled products to customers. In most cases, Cisco never sees the products its customers receive.

VENs often entail channel assemblies, where 'original equipment manufacturers' (OEMs) do not actually make their own goods. Autonomous parts suppliers make the components and independent distributors do the final assembly. The *OEM* only designs the product and manages the distributor's parts inventory.

Major auto manufacturers are also moving toward becoming VENs. They will design vehicles but not individual parts. That is what autonomous parts suppliers will do. Qualified independent suppliers will also be responsible for assembling the vehicle's major subsystems (the interior, the chassis, and so on), which the manufacturer will combine at the end. Volkswagen's radical value-chain management (VCM) experiment with Plant-X *modular consortium manufacturing design* (MCMD) or *co-location* at its truck factory in Resende, Brazil, has indeed changed the idea of what it means to be a modern business firm (Schemo 1996).

VW's autonomous suppliers have their own space at the Resende plant, their workers building trucks throughout the assembly line. Since VW's local market is small, this is also a small plant, with a scheduled output of only 100 trucks per day and only 1,000 workers, 200 of them working for Volkswagen. VW's 200 workers market, research, design and inspect quality. The other 800, who work for Delga Automotive, Eisenmann, Iochpe-Maxion, MWM-Cummings Engines, Rockwell International, VDO and other independent suppliers, do the assembly work. Each supplier accepts responsibility for its units and worker compensation, thereby sharing VW's direct cost and risk.

It is becoming increasingly difficult in a VEN to determine where one firm begins and another ends. VEN members are tightly woven together. No single firm can point to a final good or service and say: 'We did that'. VEN members perform processes rather than produce complete products. The final product (good or service) results when all these processes work together (Georgantzas 1995).

Process integration within a VEN goes far beyond traditional purchasing and outsourcing, in which a firm lets others take care of nonessential functions. Specialist VEN members perform critical processes *not* because they are unimportant, but because they are so important that the original OEM cannot afford them done in mediocrity.

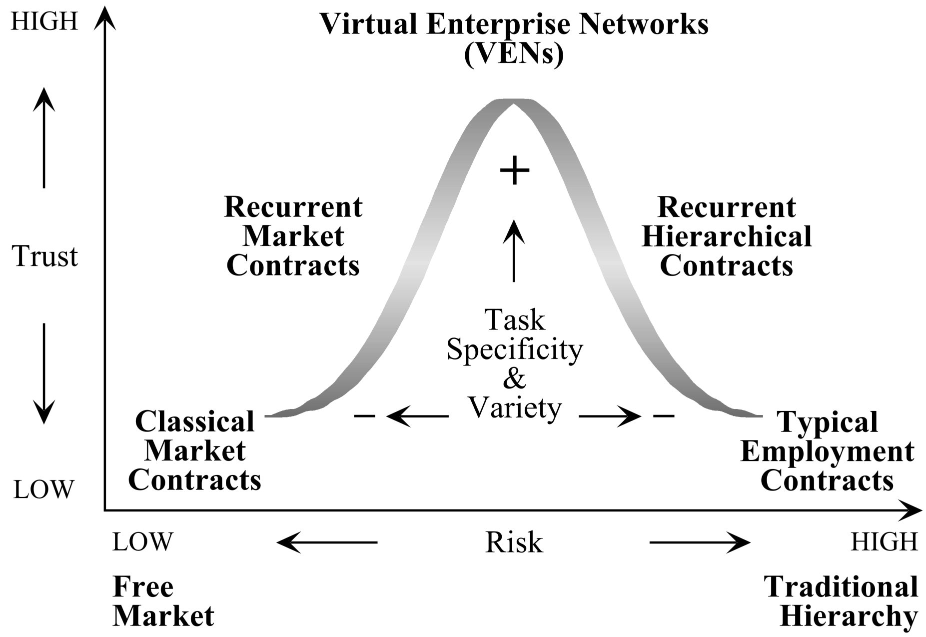

Fig. 1. Transactional exchange governance (TEG) forms along four strategic dimensions.

Table 1
Characteristic dimensions of transactional exchange governance (TEG) forms

TEG Form / Dimension	1 Sovereign market with classical contracts	2 Encumbered market with recurrent contracts	3 Virtual enterprise network (VEN)	4 Mutual trust in hierarchical contracts	5 Traditional hierarchy with work contracts
1 Asset specificity	Nonspecific	Mixed	Mixed & idiosyncratic	Mixed & idiosyncratic	Idiosyncratic
2 Contracts	Classical contracts	Recurrent contracts	Formal rule based governance	Relational contracts	Employment contracts
3 Dispute resolution	External market norms & legal system	Equity/reciprocity norms & societal legal system	Endogenously designed based on trust	Reciprocity & reputation	Internally by fiat & formal authority
4 Duration of exchange	Coincident in time	Short term	Short or long term	Medium term	Long term
5 Nature of exchange	One-time production & property rights transfer	Episodic production & property rights transfer	Sustained production & interdependence	Sustained production & property rights transfer	On-going production & rationing of wealth
6 Relationship	Limited & non-unique of free & equal parties	Unlimited & unique of free & equal parties	Extensive, unique relationships of committed parties	Extensive, unique & socially embedded	Command & obedience of legally unequal parties
7 Terms & conditions	Clear, complete, sharp in by agreement, sharp out by pay & performance	Certain & full, contingent on prior performance, with safeguards	Complementary strengths enable mutual learning among partners	Uncertain, open & incomplete, with mutual safeguards & conflict resolution	Authority & structure rule, superiors hire & subordinates obey or leave

Successful VENs enable all firms involved, each of which performs specific processes, to work together as smoothly as they would if they were one enterprise. As VENs spread, firms increasingly define themselves in terms of the processes they perform rather than the products or services they produce (Georgantzas 1995, Peppard 1999).

The ability to integrate with others is becoming a vital core competence, while new corporate cultures that value cooperation and sharing are emerging. Transforming a governance form from a traditional, product- and efficiency-centric framework to an innovative, customer-centric dynamic clockwork that incorporates e-business and radical top-line market improvement is as much a matter of mindset as information and communication technology (ICT).

Rapid information flow enabled by ICT may be the legs of a VEN's customer-focused, self-organizing (autopoietic) value chain, but not its heart. Building such a customer-centric value chain that entails cycles of self-production remains a management challenge, not merely a technology challenge. As a transport mechanism, ICT allows rapid, low-cost communication among firms. Just as important, technologies that build on the Internet, such as the *extensible markup language* (XML) help ICT systems of VEN participants mesh smoothly. VEN implications dwarf those of digital commerce, however. Both co-location and Web-enabled digital commerce are instances of a much broader value-chain management initiative to improve intra-firm communication, responsiveness and accountability through supplier integration, a source of competitive advantage (Georgantzas 2001a).

The resource-based view of the firm holds that sustainable competitive advantage stems from a firm's ability to develop and use capabilities better that its rivals. Seeing the specific capabilities required for success in its industry, the firm builds them and competes armed with them than merely on product or service. Superior product, either a good or a service, may result from a superior design capability. But the capabilities/resources that lead to sustainable competitive advantage include firm-specific knowledge (Winter 1987), core competencies, such as skills and collective learning, and management's ability to marshal these (Prahalad & Hamel 1990), and learning itself.

In their quest for competing-through-capabilities principles, Stalk et al. (1992) see neither products nor markets, but business processes as the building blocks of corporate strategy. Similarly, Thurow foresees that, although past winners were those who invented new products, in the 21st century "sustainable competitive advantage will come more out of new process technologies and much less out of new product technologies" (Thurow 1992, p. 45). Sustainable success depends on molding a firm's processes into capabilities that consistently add value to the firm's goods and services. Firms build these capabilities by investing in support infrastructures that combine and transcend traditional operations and functions.

VEN partnerships help firms focus resources on their core business. As firms strive to improve their supplier links, the cost of supporting multiple suppliers escalates. Consequently, firms try to reduce the number of their suppliers and stay with the ones who are the easiest to work with. Value-chain improvements occur primarily through the development of existing VEN member process capabilities rather than large-scale supplier switching.

VENs like industrial district SME networks are neither market-scattered competing clusters, nor appendices to large firms and conglomerates. On the contrary, they form their own customer- or market-centric industry value chains (Fig. 2), enabling themselves to respond to changing markets directly, bonding with markets through customized feedback linkages. VENs are self-organizing systems, i.e., they meet the conditions that support self-organization in complex adaptive systems (Heylighen 1999).

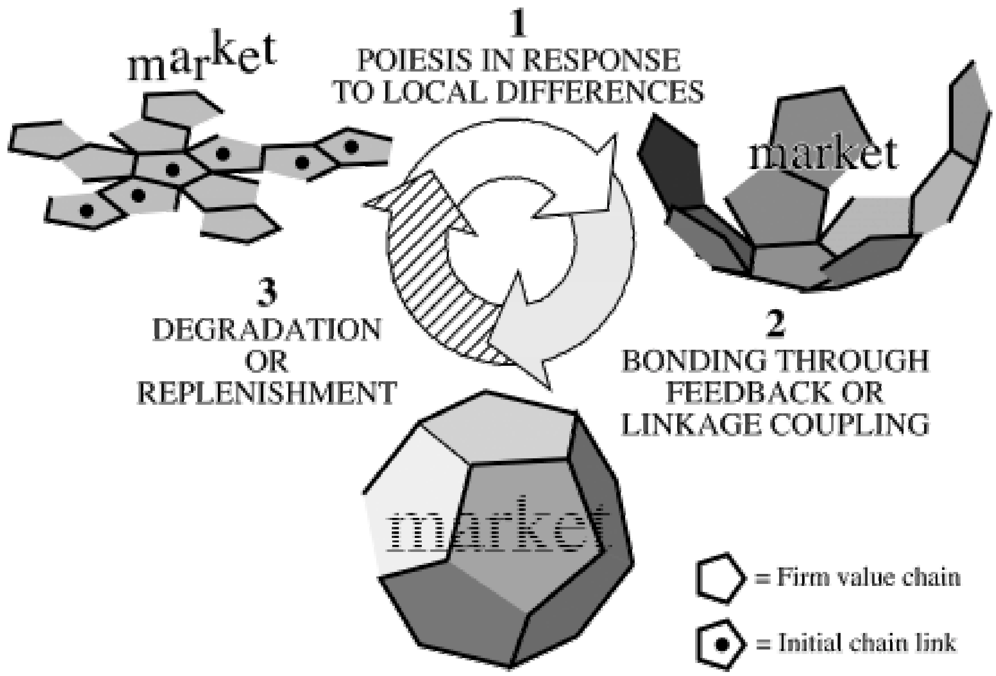

Fig. 2 Circular autopoiesis in market-centric industry value chains (adapted from Zeleny 1999a).

In its unparalleled wisdom nature creates adaptively complex self-organizing systems (SOS), which produce the dynamic (i.e., through-time) behavior patterns that physicists and life scientists see. A system is an organized group of interacting components working together for a purpose. Control over the system's organization is either centralized in a distinct subsystem, or distributed among evenly contributing components. Distributed control enables self-organizing systems to create globally coherent behavior patterns (i.e., dynamics) spontaneously out of local component interactions (Georgantzas 2001b).

What links embryos and hurricanes, the pattern of stripes on a zebra and the rhythmic contraction of your heart, or persistent cycles in real estate markets and neural networks, is that they are all self-organizing systems: their dynamics arise spontaneously from their internal structure. Their feedback-loop structure amplifies small perturbations (variations), generating behavior patterns in space and time that create path dependence. SOS dynamics is typically non-linear because of the circular or feedback-loop relationships among system components. Positive feedback leads to explosive growth dynamics, which ends when all component behavior has been absorbed into a new configuration pattern (i.e., attractor), leaving the system in a stable, negative feedback state (Sterman 2000).

The circular autopoiesis of a market-centric VEN or SME network begins with poiesis (production) in response to local differences as new customers and suppliers, new technologies and goods or services enter the scene. With the market still forming (top of Fig. 2), alternative chains develop to cover needs that the initial industry value chain incumbents do not. The rules and regulations governing new entrants adhere to the requisite manifestations of the firm and industry value chain frameworks.

As the market grows, the network's incumbents build transforming bridges across local differences identified in the poiesis process, with the market-centric VEN or SME network components bonding through feedback or linkage coupling. The system moves toward an equilibrium state, its past behavior superseded by emergent dynamics corresponding to the network's feedback-loop linkages. Although there might still be exchange between the system and its environment, enabled by distributed control, linkages that embody its internal structure determine the network's organization and dynamics. At some point in the bonding process, equilibrium is reached when all suppliers and customers are integrated. The system then becomes organizationally closed and thermodynamically open (bottom of Fig. 2).

As the market declines, rules associated with degradation or replenishment come into play. During this process, incumbent firms unable to adapt go out of business, their knowledge agents absorbed into newly emerging units in new markets. As a result of degradation (left of Fig. 2), new differences become significant in the system, and its self-organizing (autopoietic) process moves into the next poiesis-bonding-degradation cycle (Zeleny 1999b).

4. A generic TEG structure

With the structure and rules behind circular autopoiesis in market-centric networks understood, including birth, death, membership and acceptance, it becomes fairly simple to build a simulation model for such a SOS (Fig. 3). VEN or SME network bonds, i.e., VEN Bonds, is a real quantity that cannot grow forever. Every system that initially grows exponentially, eventually approaches the carrying capacity of its environment, whether food supply for moose, number of people susceptible to infection, or potential market for a good or service (Sterman 2000). As an autopoietic system approaches its limits to growth, it goes through a nonlinear transition from a region where positive feedback dominates to a negative feedback dominated regime. S-shape growth often results: a smooth transition from growth to equilibrium to degradation.

Figure 3 shows the stock and flow diagram of a *generic*, as opposed to firm or industry specific, TEG structure. In system dynamics models, rectangles usually represent *stocks*, i.e., variables that accumulate over time, such as VEN Bonds in the middle of Fig. 3. The double-line pipe-and-valve-like icons that appear to be filling and draining the stocks, often emanating from cloud-like *sources* and ebbing into cloud-like *sinks*, represent *flows* that cause the stocks to change. The bottom of Fig. 3, for example, shows the flow of firm-specific Knowledge to Diffused Knowledge that represents the process of knowledge diffusion. The single-line arrows represent *information flows*, while the circular icons depict *auxiliary constants*, *behavioral relations* or *decision points* that convert information into decisions. Changes in diffusion, for example, are coproduced over time by firm specific Knowledge and Diffused Knowledge adjusted by diffuse time. The diagram of Fig. 3 is reproduced from the actual simulation model built using the diagramming interface of *iThink*® *Analyst* 6 (Richmond & al. 2000).

There is a one-to-one correspondence between the structural diagram of Fig. 3 and the algebraic equations underlying the simulation model. Like the diagram of Fig. 3, the Table 2 equations are also the actual output from *iThink*® *Analyst* 6. The model was built by first diagramming its structure on the glass of the computer screen and then specifying simple algebraic equations and parameters for each element in the model. The software enforces consistency between the diagram and the equations, while its built-in functions help modelers quantify policy parameters and variables pertinent to managerial decision situations.

VENs economize on the cost associated with transacting Knowledge by pseudo-internalizing market exchange. Transaction cost reductions from internalization constitute their Payoff (Eq. 4, Table 2). Again, transaction costs include the costs of drafting, negotiating, monitoring and enforcing a comprehensive-claims contract as well as the cost of firm-specific Knowledge involuntary dissemination attributed to opportunism by external contractors. Payoff is equivalent to the total transaction costs avoided through forming VEN Bonds (Eq. 5, Table 2). Its initial value of

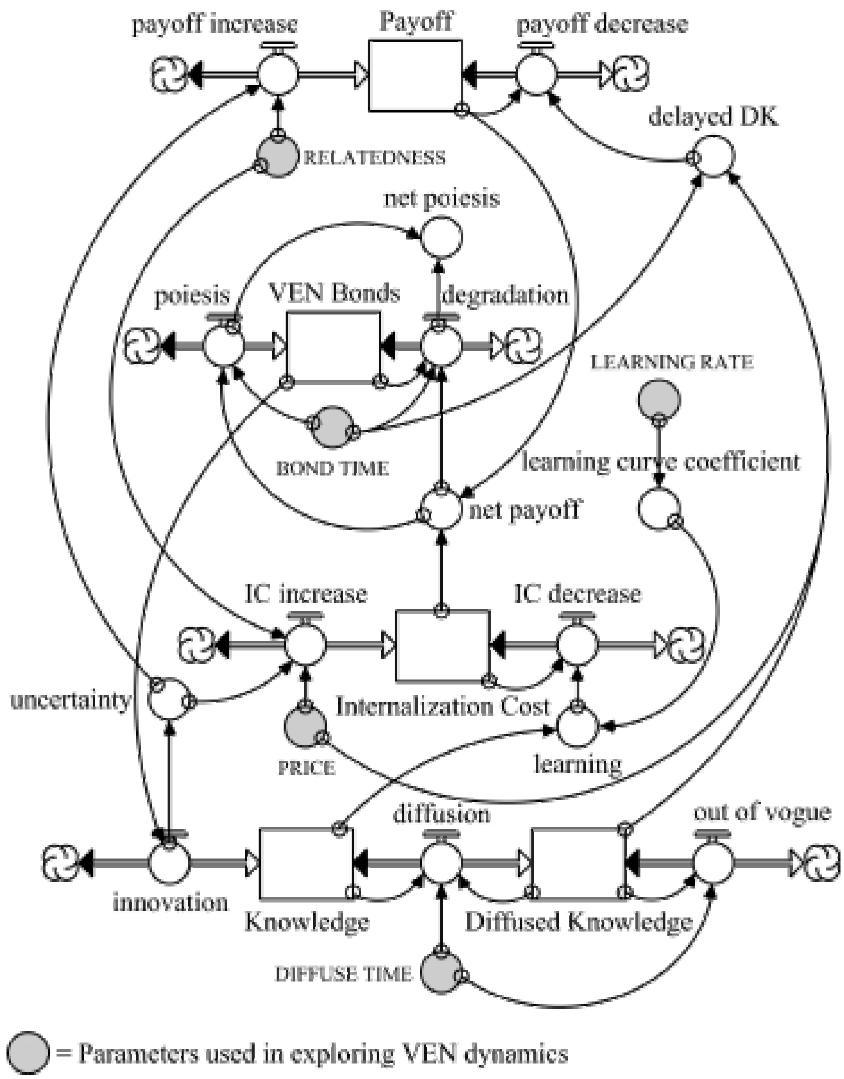

Fig. 3. A generic transactional exchange governance (TEG) structure.

one represents a dimensionless index of market failure that firms must face before and after forming VEN bonds.

The five-fold advantage in upgrading to the coaxial cable of multiple system operators (MSOs) in the TV-related industry, rather than using the copper wire of telecoms inspired the value of the relatedness parameter in Eq. 24 (Georgantzas et al. 1994). In the M&A alternative to VENs, initially, the price of a two-firm merger determines the magnitude of Internalization Cost (IC) in Eq. 2. The parameter value in Eq. 23 conveys that the price an acquiring firm A pays does not depend on the value of the target firm B acting independently, but on the synergistic outcome of their merger (or VEN bond) AB. With cash flow net of transaction costs, if relatedness holds and NPV(A) = NPV(B) = 1, then the condition NPV(AB) > NPV(A) + NPV(B) must hold too (Copeland & Weston 1983). Three is the smallest index value that will satisfy this strict inequality, indicating that the value added to firm A by bonding with firm B is 2 [i.e., NPV(AB) - NPV(B) = 3 - 1]. Clearly, this excludes unrelated VEN bonds and unrelated M&As.

Multiplying relatedness by price in Eq. 9 allows accounting for IC beyond the initial investment that VEN Bonds or other TEG forms require. Included are: the cost of learning the new integrated market and corporate culture, the cost of transferring knowledge using a pseudo-internal market, and the cost associated with controlling the newly created value chain. Neoclassical economic theory assumes that transferring firm specific knowledge is free but, in practice, sharing proprietary knowledge implies a significant cost (Georgantzas 1991, Teece 1987, Zeleny 1986). The index value of zero in Eq. 2.1 signifies that the prime determinant of IC is a VEN's cost of transactional control. After a VEN bond transition, with luck, organizational learning will cause the internal cost of controlling the newly created bond to drop back to its initial zero index value. Indeed, learning brings IC down to its initial level once VEN Bonds have been established.

Table 2
TEG structure equations

Stock or Level Variables	Eq. #
Diffused Knowledge(t) = Diffused Knowledge(t - dt) + (diffusion - out of vogue) * dt	(1)
Diffused Knowledge(0) = Knowledge {units = dimensionless index}	(1.1)
Internalization Cost(t) = Internalization Cost(t - dt) + (IC increase - IC decrease) * dt	(2)
Internalization Cost(0) = 0 {units = dimensionless index}	(2.1)
Knowledge(t) = Knowledge(t - dt) + (innovation - diffusion) * dt	(3)
Knowledge(0) = innovation {units = dimensionless index}	(3.1)
Payoff(t) = Payoff(t - dt) + (payoff increase - payoff decrease) * dt	(4)
Payoff(0) = 1 {units = dimensionless index}	(4.1)
VEN Bonds(t) = VEN Bonds(t - dt) + (poiesis - degradation) * dt	(5)
VEN Bonds(0) = poiesis {units = dimensionless index}	(5.1)
Flow or Rate Variables {units = dimensionless index/dt (dt = computation interval = 1/64 months)}	
degradation = If(net payoff <= 1) and(VEN Bonds > 0) then(max(0, VEN Bonds / bond time)) else(0)	(6)
diffusion = max(0, (Knowledge - Diffused Knowledge) / diffuse time)	(7)
IC decrease = max(0, learning * Internalization Cost)	(8)
IC increase = price * uncertainty * relatedness	(9)
innovation = 1 + VEN Bonds	(10)
out of vogue = max(0, Diffused Knowledge / diffuse time)	(11)
payoff decrease = If(Payoff <= 1) then(1) else(delayed DK)	(12)
payoff increase = 1 + uncertainty * relatedness	(13)
poiesis = If(net payoff > 1) then(max(0, net payoff * (net payoff - 1) / bond time)) else(0) {Metcalfe}	(14)
Converter or Auxiliary Variables and Constant Parameters	
bond time = 6 {units = months}	(15)
delayed DK = DELAY(Diffused Knowledge, bond time/price)	(16)
diffuse time = 18 {units = months; Moore}	(17)
learning = Knowledge ^ learning curve coefficient	(18)
learning curve coefficient = LOGN(learning rate)/LOGN(2)	(19)
learning rate = 0.8 {units = dimensionless}	(20)
net payoff = Payoff - Internalization Cost {units = dimensionless index}	(21)
net poiesis = poiesis - degradation	(22)
price = 3 {units = dimensionless index}	(23)
relatedness = 5 {units = dimensionless index}	(24)
uncertainty = pulse(innovation, 1, 100) {units = dimensionless index}	(25)

Together, Eq. 18 through 20 constitute a logistic function, which Radzicki & Sterman (1993) find appropriate for representing learning in system dynamics models. Alternatively, a graphic table or a Gompertz function might be used, but the logistic function captures and preserves the sequence of causality in the enabling effect of administrative innovation—in transition management teams, for example—on a firm's ability to bring IC down to its initial value quickly. The lower the rate of innovation, the longer it will take Internalization Cost to fall back to its initial value of zero, and vice versa.

The poiesis rate (Eq. 14) causes VEN Bonds to take off when the perceived Payoff of economizing on transaction costs exceeds the IC of establishing and running a pseudo-internal market, i.e., when the net payoff (Eq. 21) is positive. Behavioral decision theory suggests that, within policy functions (Morecroft 1988), decision makers often work with outdated and filtered information (Forrester 1961, Ch. 10, Simon 1976, Ch. 5). In VENs or other TEG forms, legal procedures further compound information filtering, yielding the frequently observed 6-month delay of equation 15.

The rate Eq. 6 and 14 are good examples of policy functions, where VEN managers decide whether they should engage asset resources in VEN Bonds. If the perceived magnitude of net payoff is positive, then VEN Bonds will increase (Eq. 14), and vice versa (Eq. 6). The poiesis rate (Eq. 14) enacts Metcalfe's Law. Robert Metcalfe founded 3Com Corporation and designed the Ethernet protocol for computer networks. His law states that the usefulness or utility of a network roughly equals the square of the number of users N or, more precisely, $N(N-1)=N^2-N$.

Ultimately, uncertainty (Eq. 25) affects managerial perceptions of net payoff when innovation in Eq. 10 yields a breakthrough. Because of differing strategies and configuration of activities (Porter 1991), VEN participants accumulate differing Knowledge (Eq. 3). Firm-specific assets and Knowledge depreciate, however, when emergent technologies drive extant key technology out of vogue (Georgantzas & Acar 1995, Godet 1987, Stacey 1984), and firm specific Knowledge is diffused (Eq. 7) to become Diffused Knowledge (Eq. 1). In times past, the frequency of knowledge diffusion had been the topic of over 1,000 studies (Sahal 1981). Recently, however, Gordon Moore, founder of Intel Corporation, has enunciated Moore's Law, which states that every 18 months, processing power doubles while cost holds constant (Eq. 17).

5. Behavior of the generic TEG structure

Initializing the model in equilibrium prevents latent artifacts of the relationships among variables from contaminating the computed behavior of VEN Bonds. Then, the built-in pulse function of *iThink® Analyst* 6 (Eq. 25) allows computing a surge of exogenous innovation-driven uncertainty at time t = 1 month. Figure 4 shows the typical dynamics of the generic TEG structure.

The shaded area on the left of Fig. 4 represent net payoff, the difference between the Payoff of overcoming impediments to market exchange and the Internalization Cost associated with controlling the expanded virtual organization that results from forming VEN Bonds. Over time, Diffused Knowledge causes Payoff to fall, while Knowledge enables learning to reduce IC. As long as net payoff is positive, multiple waves of VENs Bonds occur, causing the s-shaped growth and decline dynamics on the right of Fig. 4.

Extant firm specific competencies and routines enable some firms to adopt new technical achievements faster than other firms. Immediately, the newly acquired Knowledge makes other firms propose VEN Bonds to avoid supplier charges plus transaction costs. The prospect of internalizing market exchange causes a sharp discontinuity in the Payoff (P) curve of Fig. 4. Initially driven by bond price, IC also leaps, even higher than Payoff.

Through time, however, both P and IC decline. On the one hand, entropy considerations emerge to diffuse Knowledge, causing the P curve to fall. On the other hand, negotiations and legal arrangements cause the initially high IC curve to drop sharply. Accumulated Knowledge enables learning to deal with new integrated external markets and internal culture clashes, learning to transfer knowledge using pseudo-internal markets, and learning to reduce the cost associated with controlling newly created VENs. Soon (t_1), the perceived Payoff of economizing on transaction costs exceeds the cost of establishing and running a pseudo-internal market. This makes net payoff (the shaded area of Fig. 4) strictly positive, causing VEN Bonds to rise.

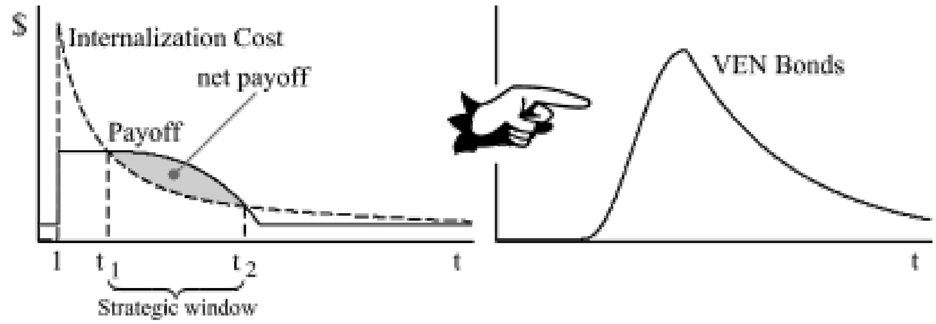

Fig. 4. Typical VEN dynamics produced by the generic TEG structure.

Without any breakthrough transformation, however, the IC curve falls toward its initial index value of zero, where its prime determinant is the cost of controlling the newly formed VEN. Similarly, with the acquired Knowledge diffused, the P curve also declines, lowering transaction cost down to a point where IC is equal to or exceeds the external supplier charges plus the transaction costs. Then (t_2), to remain competitive, firms gradually stop forming and actually start degrading their VEN Bonds, closing the strategic window of Fig. 4.

5.1 Exploring the generic TEG structure

The generic transactional exchange governance structure of Fig. 3, as basic as it is, yields important insight into observed VEN dynamics. Five sets of computed scenarios allow exploring the behavior of the generic TEG structure, each set corresponding to five changes in the shaded parameters of Fig. 3. Table 3 shows the specific parameter values used for each simulation run within each computed scenario set, yielding a total of twenty-five simulation runs.

Table 3
Computed scenarios exploring the generic TEG structure

Computed scenario set #:	1	2	3	4	5
Simulation run #	learning rate {dimensionless}	price {dimensionless index}	relatedness {dimensionless index}	bond time (ad hoc) {months}	diffuse time {months}
1	0.4	1	1	0.01	2
2	0.5	2	2	0.10	6
3	0.6	3	3	1.00	10
4	0.7	4	4	3.00	15
5	0.8	5	5	6.00	18

Figure 5 shows the response of the generic TEG structure, attributed to the sensitivity of IC and VEN Bonds to changes in the learning rate. The system begins in equilibrium with both IC and VEN Bonds equal to zero. At the start of t = 1 month, a surge of exogenous innovation-driven uncertainty suddenly increases IC, which begins to gradually fall, depending on the magnitudes of the learning rate. The higher the learning rate, the sharper the decline in IC.

IC reduction makes forming VEN Bonds feasible, so they rise in response to an increase in poiesis, which responds to a positive net payoff, the difference between P and IC. The higher the learning rate in Fig. 5, the sharper and the earlier the rise in VEN Bonds. However, as the IC curve falls, the P curve also declines as Diffused Knowledge accumulates, to a point where firms stop forming but begin degrading their VEN Bonds.

The consequences of the generic TEG structure dynamics are profound for VENs. First, the transactional exchange governance process creates significant amplification. Given the initial response of the IC decrease to the learning rate magnitude (Fig. 3), at a learning rate of 80 percent, the average *amplification ratio* (the ratio of the maximum change in output to the maximum change in input) is 3.09 for the diffusion rate and 0.51 for the poiesis rate, respectively (bottom right of Fig. 5). These amplification ratio values show that a one-percent increase in IC reduction causes a 3.09 percent increase in diffusion and a 0.51 percent increase in poiesis, respectively.

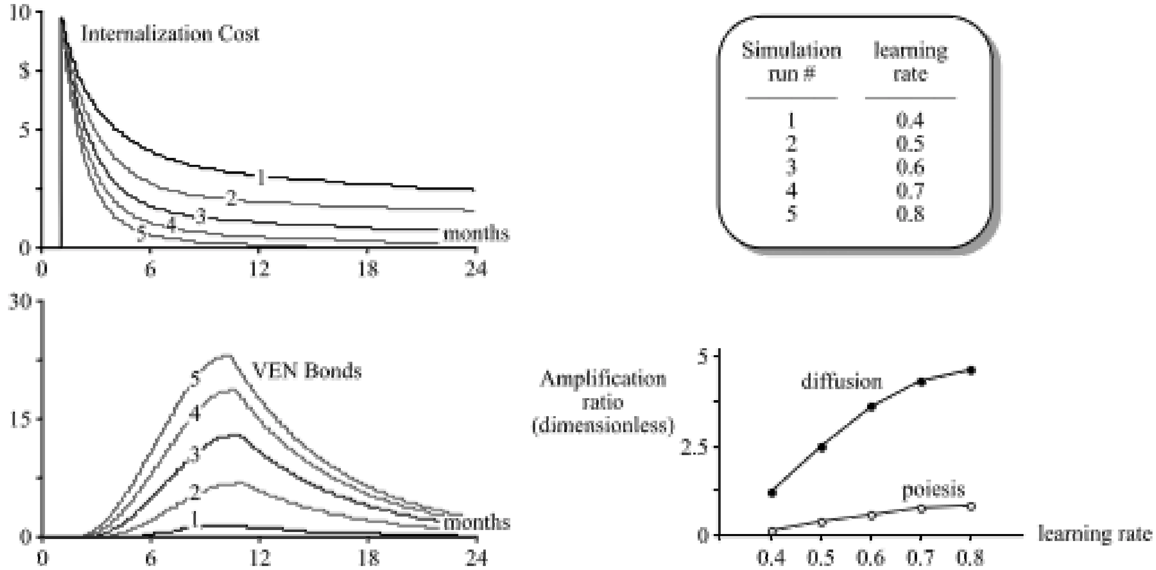

Fig. 5. VEN sensitivity to learning.

Second, amplification is temporary. In the long run, a one-percent increase in IC reduction leads to a one-percent increase in knowledge diffusion. During the disequilibrium adjustment, however, firm-specific knowledge diffusion overshoots IC reduction due to learning by almost a factor of five. In their bonding phase, VEN members must lose a lot of firm specific knowledge to potential competitors. Yet, without trust and information sharing there can be no poiesis, no bonding, no VEN.

Figure 6 shows the response of the generic TEG structure, attributed to the sensitivity of IC and VEN Bonds to changes in price. While learning directly affects IC decrease, price directly affects IC increase (Fig. 3). Hence, the higher the initial internalization price, the higher IC's magnitude gets in response to the uncertainty step jump at time t = 1 week (top left of Fig. 6).

The price of admission is as real in VENs as in M&As. Without any barriers to entry rules, such as those VENs use, qualified firms will eagerly form VEN Bonds. Conversely, the higher the initial price of admission or asset resource requirements, the fewer the VEN Bonds qualified firms will form. The amplification ratio values of diffusion and poiesis, with respect to their input, IC increase, confirm this. On average, a one-percent decrease in the IC increase rate causes a 2.61 percent increase in diffusion and a 0.37 percent increase in poiesis, respectively (Fig. 6).

Figure 7 shows the response of the generic TEG structure to changes in relatedness, which directly affects both the payoff increase and the IC increase rates (Fig. 3). Hence, both the Payoff and the IC stocks increase in response to the uncertainty step jump at time t = 1 week (top of Fig. 7). Similarly, the higher the qualified firm relatedness is, the more VEN Bonds qualified firms form. Again, the amplification ratios of diffusion and poiesis confirm this, with respect to their IC input increase. On average, a one percent increase in the IC increase rate causes an 35.01 percent surge in diffusion and a 5.14 percent increase in poiesis, respectively (Fig. 6).

Figure 8 shows the sensitivity of the generic TEG structure to changes in bond time. The now ad hoc, as opposed to incremental, changes affect both the Payoff and the IC stocks. According to the results, the faster a VEN forms the faster and sharper its degradation (lower left of Fig. 8).

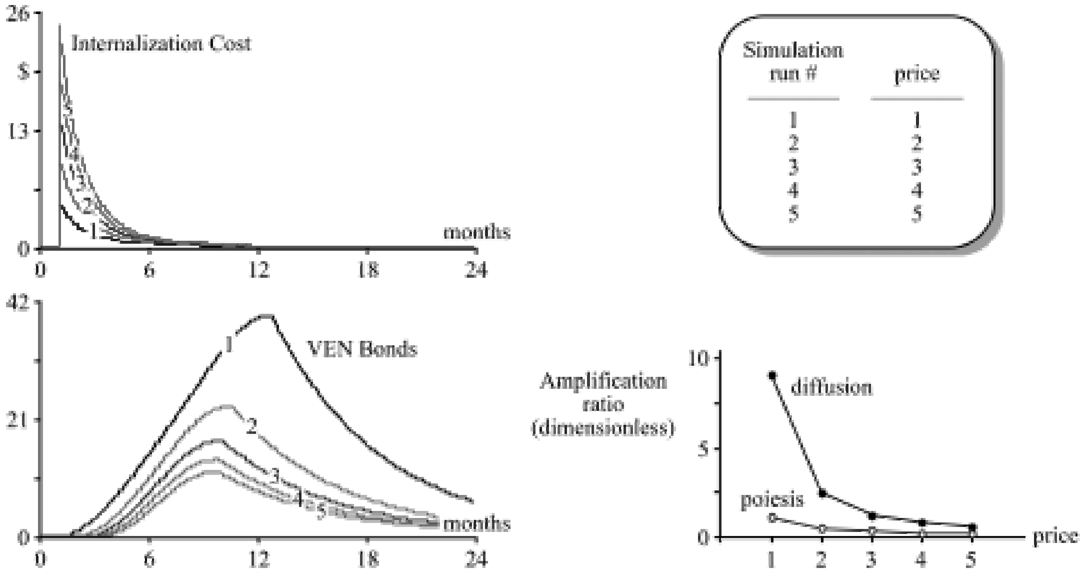

Fig. 6. VEN sensitivity to price.

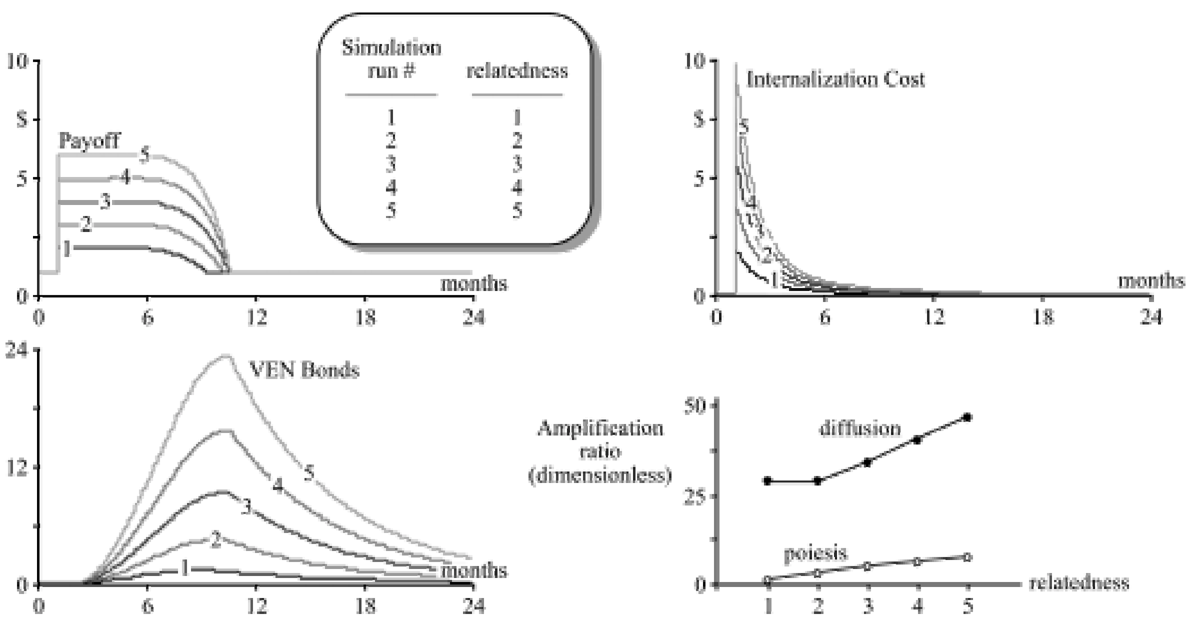

Fig. 7. VEN sensitivity to relatedness.

The shorter the bonding time is, the faster the perceived VEN Payoff declines (top left of Fig. 8). Short bonding times deprive VENs from learning and innovation, thereby reducing their chance to reduce their IC. On the top right of Fig. 8, IC initially declines but, without innovation and learning, it stays too high to make VEN sustainability viable. According to these results, can one expect to see VENs form and dissolve in days or even hours or minutes? Even if ICT enables customers to join a VEN's internal markets quickly, what might be the sociopoliticoeconomic and legal implications of instantly forming and dissolving industry value chains? What might be the knowledge-worker requirements for such industry value-chain time-compression dynamics?

The bottom right panel of Fig. 8 shows the amplification rate of Knowledge diffusion and poiesis plotted over the price/learning rate ratio. When the initial price of admission is low and/or the learning rate is high, then the amplification ratio is 7.60 for diffusion and 8.76 for poiesis, respectively. A one-percent IC increase causes a 7.60 percent surge in diffusion and an 8.76 percent surge in poiesis, respectively. Conversely, when the initial price of admission is high and/or the learning rate is low, then the amplification ratio is 0.10 for diffusion and 0.14 for poiesis, respectively. Now, a one-percent IC increase causes only a 0.10 percent increase in diffusion and a 0.14 percent increase in poiesis, respectively.

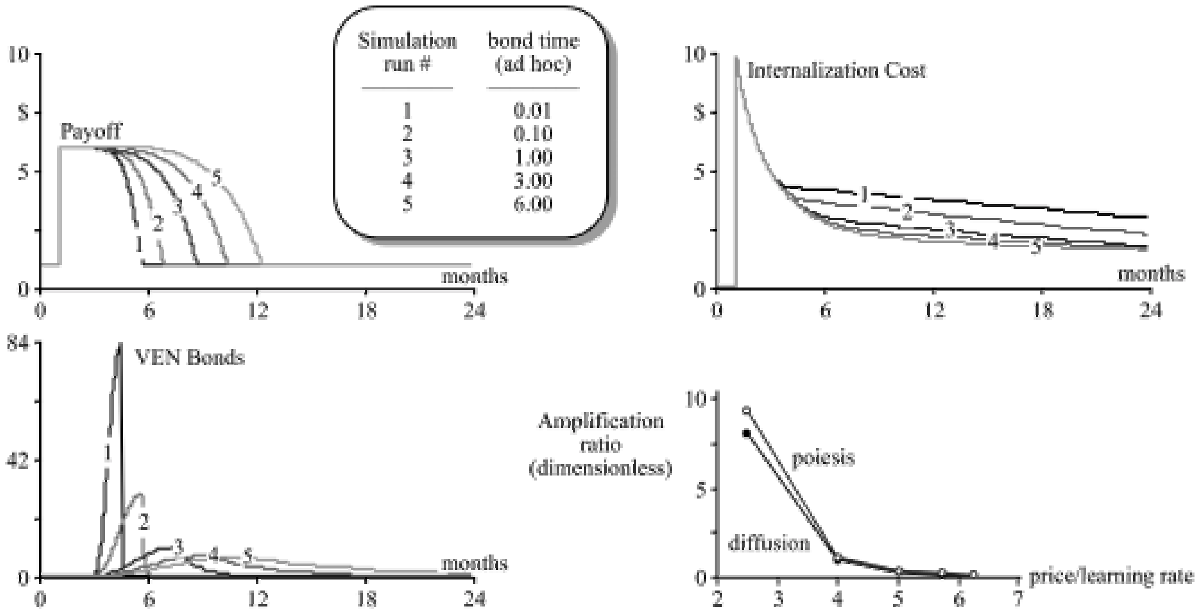

Fig. 8. VEN sensitivity to bond time.

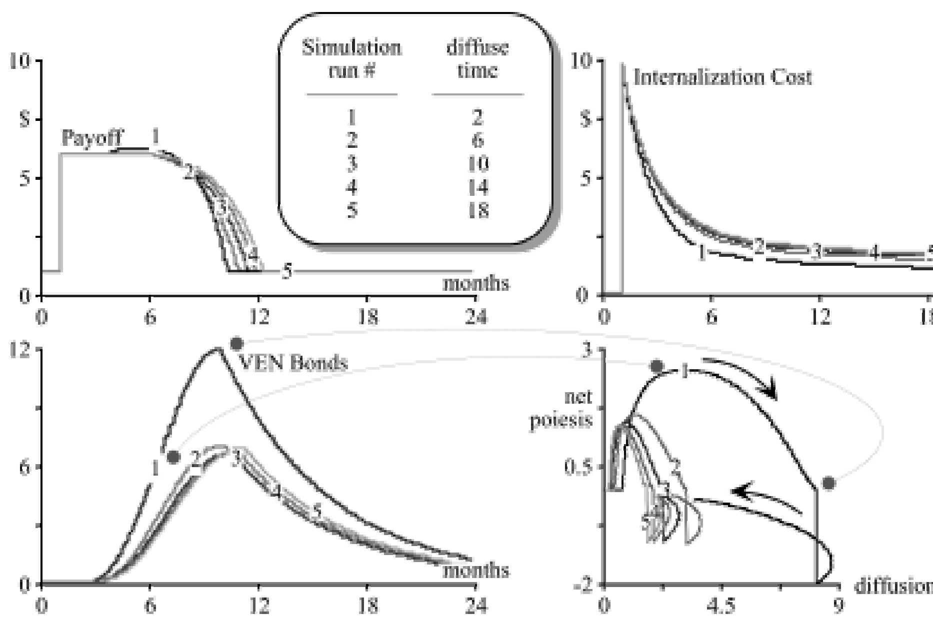

Fig. 9. VEN sensitivity to diffuse time and the knowledge diffusion-net poiesis phase plot.

Talking about time compression, Fig. 9 challenges Moore's 18-month Law. A short Knowledge diffusion time causes Payoff first to rise above its initial step increase and then to decline fast. Moreover, the short diffusion time also drives IC down even faster. Combined, the high Payoff and a low IC cause the net payoff (Fig. 4) to rise, thereby causing VEN Bonds to grow fast to reach a high level.

The bottom right panel of Fig. 9 shows the phase plot of net poiesis curves over Knowledge diffusion, with stable equilibria near zero. The two arrows on the graph show the direction of the net poiesis curve as a function of knowledge diffusion through time.

Initially, positive (reinforcing) feedback dominates the system in the region where net poiesis has a positive slope, while negative (compensating) feedback is dominant where net poiesis has a negative slope. The net poiesis rate rises nearly linearly when diffusion is close to zero. VEN Bonds' behavior in this region resembles pure exponential growth (bottom left of Fig. 9). As VEN Bonds increase, net poiesis continues to rise, but at a declining rate. At some point, net poiesis reaches a maximum (bottom right of Fig. 9). This point comes at a lower VEN Bonds density than the peak in the poiesis rate because degradation is increasing at an increasing rate. The peak of the net poiesis curve on the phase plot corresponds to the inflection point in the trajectory of VEN Bonds in the time domain, i.e., the point at which VEN Bonds is rising at its maximum rate.

Beyond the VEN Bonds' inflection point, net poiesis, while still positive, drops, falling to zero just when VEN Bonds reach their peak. If the number of VEN Bonds continued to rise, individual firm profit would become scarce. As net payoff turns negative, degradation exceeds poiesis, and the number of incumbent VEN Bonds fall back toward zero. The equilibrium at the point where diffusion nears its maximum is thereby an unstable one.

As VEN Bonds begin to decline exponentially, their density decreases causing net poiesis to grow back up again as both the degradation and the diffusion rates slow down. Net poiesis reaches for a second maximum, approaching its stable equilibrium point where both it and knowledge diffusion equal zero.

6. Discussion and conclusion

A system dynamics model in the form of a generic TEG structure examined how changes in their business environment might determine the success of VENs or kill them. The model used policy parameters of organizational innovation and internal control costs, which affect VEN dynamics. Additionally, borrowing ideas from the transaction cost economics branch of organizational economics, particularly its internalization theory extensions, allowed exploring the effect of internal cost of control on governance choices.

The essay aimed at helping business researchers and practitioners reperceive the structure and implications of VENs as strategic phenomena. The capacity of system dynamics modeling to reintegrate the content and process perspectives of strategy might indeed turn it into a new paradigm for competitive advantage. Also, the quantification required for computing scenarios by simulating changes in a firm's competitive environment forces specificity, i.e., clear thinking. Following the description of model structure, computed scenarios assessed the sensitivity of the generic TEG structure. The simulation results show the dynamic evolution of transactional exchange governance that might create alternative futures for VENs, pointing to the potentially rich contribution of system dynamics to exploring governance forms beyond the ideal-type forms of markets and hierarchies that dominate TCE analysis.

Although helpful in evaluating alternative governance forms while exploring strategic dependencies among firms, TCE suffers from the static view of strategy, paying little attention to the dynamic effects of organizational issues and the internal cost of control on the choice of governance modes. Also, TCE research overlooks the effects of governance on revenue and profitability, particularly in highly uncertain situations where hierarchies begin to look like clans and networks of contracts. The model described here overcomes these flaws only partially, but can be easily extended to incorporate explicitly other governance forms that create internal markets. With joint ventures (Hennart 1988, Pisano 1990), for example, implicit in its framework, the model posited technological innovation, administrative innovation and the internal cost of control as the primary causes of firms forming VENs. Then, the simulation results showed how the dynamic evolution of governance might affect VEN sustainability.

Modeling the effects of Zeleny's poiesis-bonding-degradation cycle produced results relevant to both strategy research and practice in any industry. Specifically, in response to Porter's quest for "a dynamic theory of strategy"(1991, p. 115), first, the model shed some light on the dynamic chain of causality of what might be the beginning of a dynamic theory of VEN strategy formation. Second, it helped to better understand the degree of stickiness or inertia in competitive positions, i.e., how important a burst of innovation can be. Third, with its cloud-like sources and sinks, and with its broad but coherent structure for modeling strategic situations, system dynamics provides the necessary flexibility for deciding on "an important theoretical issue... where in the chain of causality to best cut into the [strategy] problem" (Porter, 1991, p. 115). These are some key reasons why the old strategy rules will no longer apply, regardless of the industry in question. VENs with short bonding times might transform sustainable competitive advantages to temporary ones. Firms can outsource, deplete their physical assets, and morph into new configurations and relationships with other firms to lower transaction costs. Those who cling to the industrial models of the past might find hard sledding in the marketplace of the future.

In conclusion, system dynamics modeling can improve our understanding of the dynamic processes by which firms perceive and sustain superior performance over time, and make nurturing plural rationality the new defining characteristic of economic inquiry. Future TCE studies will easily reap the opportunity to reintegrate the content and process perspectives of strategy if they accept the integrative nature of human systems and the interdependence of administrative and technical knowledge in sustaining superior performance. That might radically improve the extant management technology of our core industries.

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