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A chemistry of organization: Combinatory analysis and design[1]

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Abstract

This paper is a response to the call for models of organization design as a science revealing the inner composition of organization and specifying the laws to be respected when crafting it.

It maintains that the needed science is a chemistry of organization, addressing the combination of 'organizational elements' playing a role analogous to that of chemical elements in composing a variety of substances. Drawing both on classic organization design theory and on configurational and complementarity-based approaches, the paper specifies a set of basic organizational elements and a set of combinatory laws regulating their effective combinations. Testable propositions are derived on the necessary and sufficient conditions that the composition of organizations should respect for achieving high levels of efficiency and innovation. These propositions are tested empirically on a sample of firms, using an innovative application of Boolean algebra.

Keywords: organization design, configurational approach, complementarity, fit, Boolean algebra.

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Introduction

Design has always been an important component of organization studies (e.g. Thompson 1967; Galbraith 1977; Mintzberg 1979), and it has recently gone through a phase of revitalization, with new contributions both in business administration (e.g. Hatchuel 2001; Romme 2003; Boland and Collopy 2004; Van Aken 2004; Grandori and Soda 2006; Burton et al. 2006) and organizational economics (Roberts 2004).

This paper assesses some core features of classic and emergent approaches to organization design, and identifies a need for developing a new approach that responds more closely to the standards of a science of design. In particular, by comparing classic and recent approaches we identify a fundamental shift in the definition of the design problem: from the comparative assessment of historically given, frequently occurring, 'forms' of organization able to fit certain recurring circumstances (i.e. organization by product or function or matrix, hierarchy versus market versus clans, mechanistic versus organic systems, etc.); to the definition of design rules and processes capable of generating solutions, able to fit any given particular situation.

This shift promises to deliver an organizational engineering or architecture more proximate to a science of design than we used to have in the field. At the same time, it faces new challenging questions, not satisfactorily answered yet. In this respect, two important challenges will be addressed in this paper.

First, what is the precise nature of these rules or laws generating superior organizational solutions? Among the rules considered in the previously cited contributions, some are about the social process among decision makers – i.e. how the players may talk to improve the attractiveness and creativity of the construction; while others are about how to combine organizational attributes – i.e. to what extent to employ hierarchy, teamwork, programs, pay for performance, specialization by function or product, etc. Both types of rules are relevant. This paper concentrates on the latter types of rules: the 'technical' rather than 'relational' rules that should be respected in designing organization. In fact, previous contributions have illuminated more the type of social and cognitive processes that may help design as a decision making process (Romme and Endenburg 2006), while much less has been said on the substantive 'technical' laws of combination that any solution may have to respect. These substantive basic rules of combination are arguably a component of design that can be conceived as a science: as much as an architect, while designing a house, should respect the basic laws of the static of construction and of physics; or as much as a chemist, devising a new drug, should respect the basic laws of chemistry; so the organization designer, while devising organizational arrangements, should respect some basic laws of composition of organizational elements.

Second, the paper addresses the problem of specifying the nature of organizational components or elements to be combined: what are the ‘building blocks’ of organization? How can they be conceived to predict their capacity of linking to each other and to produce different results?

In response to these questions, the paper develops a ‘chemistry of organization’: a science specifying how the basic elements composing organization systems can be defined, how they can and cannot be combined, what results they produce in different combinations.

This science fills a gap in recent design-oriented organization research concerned with organizational combinations, as it offers a theory for predicting combinations, something that has not been provided so far, neither in the configurational tradition in organization science, nor in the complementarity-based tradition in the economics of organization.

The paper is organized as follows. The first section is devoted to reviewing the achievements and limitations of the former approaches interested in organization design as combination of elements. In the first section we also highlight the specific contributions of these approaches that we retained to construct our combinative approach complementing those traditions and overcoming their limitations. The second section outlines some core propositions of the new science of ‘organizational chemistry’. The final section presents an empirical study on a sample of firms, providing an initial test of those propositions employing a set-theoretic methodology.

Constructing a Combinative Approach to Design: Inputs from Earlier Perspectives

Various important approaches to organization design have conceived, implicitly or explicitly, organization forms as systems of interconnected attributes. These approaches constitute the starting scientific basis for our contribution, aimed at identifying basic elements of organizing and at specifying general combinatory laws among them.

In the most important classic organization design paradigm, structural contingency theory, the effective shape of organization has been seen as a ‘consistent’ set of attributes, which fit to some relevant states of world. ‘Attributes’ typically included criteria for specializing units and modes for connecting them (more or less intense use of lateral communication, hierarchy, rules and procedures, teams, liaison roles, integration units, etc.) (Thompson 1967; Mintzberg 1979). The contextual variables, which those attributes should be contingently designed to, included environmental dynamism and uncertainty, strategies, technology, type of interdependence, system size. Organizational attributes and contextual variables have been connected through the notion of fit, understood in at least three ways in contingency studies (Drazin and Van de Ven 1985): selection fit, implying that structures misaligned with context will simply be selected out; interaction fit, understood as the bivariate interaction between pairs of context and structure variables affecting performance; systemic fit, understood as the multivariate interaction of multiple structural characteristics and multiple context variables affecting performance.

These notions of fit, as well as the notion of organization forms as ‘syndromes of attributes’, are traceable also in another important approach to organization design, namely transaction cost economics. That approach has delivered two contributions, not present in classic organizational design, that are particularly useful for our purposes. First, it has enlarged the portfolio of organizational attributes, by including incentives and price-like elements. Second, it has partitioned attributes into classes with specified, different, organizing properties, thereby defining families of attributes that ‘differ in kind’ (Williamson 2004). Typically, three kinds of attributes have been identified: market-like, bureaucratic and clan-like (Williamson and Ouchi 1981). These attributes were constructed in part by observing institutionalized, frequently adopted, packages of organizing techniques, and in part by assuming that attributes are consistent if they are ‘similar in kind’. Williamson (1991b) has been particularly explicit on that, and even stated the impossibility of ‘selective intervention’, namely the impossibility to infuse attributes of different kinds into the same organizational system – for example, and in particular, to infuse market elements into firms, seen as the realm of plans and hierarchy.

Of these two classical approaches to organization design, some ideas will be retained here, while some others will be put under revision. We retain the idea, common to both, that an organizational solution can be conceived as an array of ‘attributes’ – which we are going to define more precisely. We also acknowledge the need for defining what the ‘kinds’ or ‘types’ of attributes are, to be able to talk about combining elements that are ‘similar’ or ‘different’. However, we shall extend and refine the received three-fold classification in order to assess similarities and differences more precisely. We shall more radically question, instead, the ideas that organizational attributes can effectively combine only if they are ‘similar in kind’. In fact, theoretically, it is not clear why similar ingredients should be more complementary than different elements; empirically, ‘hybrid’ and ‘ambidextrous’ organizational solutions increasingly characterize the economic organization of firms. As to the notion of fit, we shall build on developments of the ‘systemic fit’ notion made available by the configurational and complementarity-based approaches illustrated below.

Two important new perspectives have been more recently developing in the direction of a combinative approach to organization design: the ‘configurational’ approach in organization studies; and the ‘complementarity-based’ approach in organizational economics.

The ‘configurational’ evolution of structural contingency theory (Miller and Friesen 1984; Meyer et al. 1993) has engaged in research on the actual combinations among wide arrays of organizational devices (actually, devices of all sort, from formal rules and policies in budgetary processes or in personnel management, to task forces and committees, to environmental scanning procedures, to central staff units, to the use of equity, and so on and so forth) and correlated these combinations with indicators of performance. These studies have hypothesized and tested that deviations from 'ideal' organizational configurations for a particular environment should result in lower performance (where the 'ideal' is typically identified empirically as the top performing configuration in a sample). Configurational studies provided a contingency approach that addressed some of the limitations of earlier contingency theory, but also lost some of its strengths. In particular, the configurational approach offers three contributions specifically useful for our purposes. First, it considered the possibility of interaction among organizational traits, rather than just pair-wise relations between organizational traits and environmental or otherwise external traits, thereby employing a notion of 'systemic fit' (Drazin and Van de Ven 1985). Second, it admitted the possibility that more than one combination of traits might be effective under the same circumstances, stressing the concept of equifinality (Gresov and Drazin 1997). Third, it admitted the possibility of non linear and non monotonic relationships among the values of organizational characteristics (Meyer et al. 1993). On the weakness side, the configurational approach lost the capacity of predicting which combinations are going to be effective under what circumstances and why, a capacity that classic contingency theory derived from the information processing theory of organization.

The complementarity-based approach to organization design, originating in organizational economics, has been pointing in a similar direction. Organizational 'attributes' have been more explicitly conceived as 'practices': packages of techniques, typically including structure, routinized action and know-how. In empirical studies, large sets of practices have been considered, such as teamwork and incentive pay, flexible job assignment and knowledge management (Laursen and Manke 2001; Ichniowski et al. 1997); or process and project organization, horizontal integration, delayering, outsourcing, and alliances (Whittington et al. 1999).

The notion of fit among attributes has been extended and made more precise through the important notion of complementarity among organizational components. 'Complementarity' is a relation between elements whereby applying one practice raises the value of employing another practice (Milgrom and Roberts 1995). This design criterion has, in principle, many advantages: it includes interactions among organizational attributes (systemic fit), and not only their pair-wise fit with exogenous conditions; it specifies clearly what 'consistency' and 'systemic fit' mean; it is wider than consistency by 'similarity in kind' as complementarities can also stem from differences.

However, among the limitations, the complementarity-based assessment of configurations is characterized by the same ‘theory loss’ as configurational studies: there is no theory allowing prediction and explanation of which organizational practice is complementary with which other. In the lack of that theory, the way of establishing which combinations are effective has been based only on the frequency of occurrence of combinations and their correlations with performance. However, in this way the complementarity argument is tautological: if what is complementary is defined as what performs best in combination, than by definition deviations from those high performing combinations entail lower performance; i.e. the explanatory law is inferred from the very pattern it should explain.

Hence, we will retain some of the lessons of configurational and complementarity-based design approaches, in particular, the complementarity-based notion of systemic fit and the concept of equifinality; but we intend to go beyond, by providing the following contributions (as summarized in Figure 1):

1. specifying the fundamental properties of the organizational attributes to be combined, so as to obtain an analog of the ‘periodic table of elements’ used in chemistry;
2. providing a theory-based ex-ante prediction of what the effective (and eventually equifinal) combinations are, arguably an important scientific input to design;
3. distinguishing what organizational elements in what combination are necessary and/or sufficient for performance, thereby escaping from a mere frequency-based approach to the identification of organizational configurations;
4. using an innovative methodology to support such an approach (see data analysis section on Boolean comparative analysis).

FIGURE 1 ABOUT HERE

A Basic Chemistry of Organization: Organizational Elements and Combinatory Laws

Classifying organization forms using any observable difference among real firms, or other institutions, is a useful part of organization science, as much as the classification of species is a useful part of natural science. We are proposing to complement it with a theory-based chemistry of organization. The latter starts from some analogue of natural elements for getting to (and explaining) the fundamental structure of the matter. This is a revolution that organization theory has not gone through yet. Organizations are artificial rather than natural systems though. So we conceive organizational chemistry as a 'science of the artificial' (Simon 1969), whose laws set limits and give basic guidelines on how to design effective systems, rather than only describing which substances any system may be composed of.

The construction of the model will address first the definition of organizational elements and, second, the illustration of combinatory laws.

Organizational elements

Organization theory has focused, for a long time, on the measurement of the dimensions of organized 'bodies' or entities, rather than on the microscopic structure of elements composing them. Measuring the degree of centralization or formalization is certainly not useless, but it is like measuring the height and weight of a person, not the molecules composing her blood or tissue. As said, we wish to shift at the micro-level of components in order to distinguish them into 'types' or 'kinds' with known properties.

Because of its emphasis on attribute similarity/dissimilarity in kind, and the partially worked out connection with the principles of behavior infused into organized systems, we are going to use as a starting point the classification received from organizational economics among the following types of attributes:

- *'market-like' attributes*, including price-like devices and control by exit (Von Hayek 1945; Hirschman 1970; Zenger and Hesterly, 1997) capable of infusing 'highly powered incentives' and of coordinating action with minimal communication;
- *'bureaucratic' attributes*, including the Weberian 'attributes' of formal vertical and horizontal division of labor and of coordination by rules, plans and central ad hoc decision making (Ouchi 1980; Williamson 1985), infusing predictability, transparency, and arbitration capacity while economizing on knowledge and information sharing;
- '*collective' and 'communitarian' attributes*, including peer group governance, knowledge and value sharing (common culture), joint decision making, and norms of reciprocity (Ouchi 1980; Butler, 1982), infusing identity, cohesion and complex problem solving capacity.

We shall extend and refine this starting classification of attributes, though, by using insights from the organization theory tradition. In fact, organization theorists have observed at least two anomalies with respect to the three-fold classification of organizing attributes produced by organizational economics.

First, the ‘third type’ of attributes collapses together at least two organizing principles and techniques that are theoretically different in their properties and not highly correlated in practice: communitarian culture-based governance and democratic peer-group governance (Alvesson and Lindkvist, 1993). In fact, cultural elements have to do with the ‘programming of the mind’ (Hofstede 1980), the homogeneity of values and objectives (Schein 1985), the ‘communal sharing’ of artifacts, practices and knowledge (Fiske 1992). Communitarian governance integrates actors by homogenizing judgments and interests through identity building and knowledge sharing practices (Fiske 1992; Kogut and Zander 1996). By contrast, things like equally distributed property and decision rights (Butler 1982), participation and representation of different knowledge and interests in decision making (Lammers and Széll 1989),‘voice giving’ procedures, fair procedures and processes for conflict resolution (Greenberg 1990), are typical ingredients of democratic governance, aimed at integrating the different judgments and interests of multiple actors through representative devices, and as such are increasingly important in modern knowledge-intensive organization (Harrison and Freeman 2004).

Second, the notion of ‘bureaucracy’, and even of ‘hierarchy’, as employed in organizational economics is also too broad and Weberian, and collapses together two modes of organizing that are known to have different properties and to be rather uncorrelated in practice: the structuring of activities through formal documents, standards and allocation of rights and obligations; and the specific configuration and source of those rights' allocations. In fact, a formal, and even hierarchical, structure can combine with ‘principals’ being at the ‘base’ (as in representative bureaucracies and cooperatives) (Gouldner 1954; Blau and Scott 1962) rather than at the ‘top’ (as usually assumed); and decision rights are often more centralized in informal systems (from family firms to informal sub-contracting) than in formal ones, also because decentralization in large systems requires formalization (Pugh et al. 1969).

Hence, we shall distinguish democratic elements from bureaucratic rule-like elements on one side, and from communitarian elements on the other. As a result, we stipulate that there are ‘differences in kind’ among at least four types of organizational elements so defined:

- market-like elements, including price-like and control-by-exit devices;
- bureaucratic elements, including formal rules and plans, and articulation of the division of labor;
- communitarian elements, including knowledge and value sharing, and common culture;

- democratic elements, including the allocation of ownership, decision and representation rights.

It's important to make clear and stress a couple of features of this typology, which is going to play the role of a 'Table of elements' in our chemistry of organization.

First, the four categories are conceived as types of elements and not as types of institutions, or 'discrete structural alternatives' themselves (as it is common thinking in new institutional economics). In the combinative approach that we are proposing, all real institutions are made of 'practices' that embody these elements in various degrees – and usually further mixed up with other collateral 'substances' that may facilitate their absorption but are not central to our analysis (e.g. implementation devices, social acceptance caveats, and the like).

Second, there is no pretense that this four-fold Table of elements is exhaustive or unique. Even in natural science new elements can always be (and have been) discovered; and classification systems with higher level of detail, or oriented to other purposes, can always be developed. This must be all the more valid for artificial elements. We are just proposing one way, rooted in previous analyses, of classifying the humanly devised artifacts that are employed in organizing as 'elements' with known general properties, so that combinatory laws can be worked out.

Third, elements are typically infused into organizational systems through the application of 'practices'. Any real practice can, in principle, embody more than one type of element. However, for the purpose of simplicity, in the operationalization of the framework in the empirical study presented in this paper, we will select and measure practices that can be considered 'carriers' of one (dominant) element. For example, 'pay for performance', and 'outsourcing' practices will be considered carriers of market-like elements. More refined analyses with multi-element practices would certainly be possible and worthwhile, but would not change the logic of the model.

Fourth, in order to provide a usable chemistry, each element will be further characterized by a number, as in chemical formulas, indicating how many atoms of that element characterize the formula. Thus, convening to indicate elements in capital letters and the number of doses (or atoms) with a small subscript, the generic organizational formula can be written in the form M_x- B_y – C_z – $D_{w.}$ In the empirical study, we propose a way of operationalizing and measuring the notion of 'one dose' or 'one atom' of an element.

The relationships between types of organizational elements, the principles of behavior they infuse into organization, and a set of contemporary relevant organizational practices predominantly containing each element are summarized in Table 1, along with the references to the studies that have highlighted and documented those relationships.

TABLE 1 ABOUT HERE

Combinatory laws

The dominant hypothesis in organizational economics about combinatory laws is that complementarities mainly stem from similarity. Hence, the less varied in kind the practices are in the same system, the better (Williamson 2004). Even though in the Milgrom and Roberts (1995) seminal article, there is no explicit theoretical argument suggesting that complementarity should stem from similarity, they also end up, in their examples, considering practices 'of the same kind' as complementary – e.g. 'mass production' practices versus 'flexible manufacturing' practices.

However, empirical research, including that inspired by the complementarity view, has yielded results that suggest elements of different kinds can be successfully combined.

For example, Whittington et al. (1999) examined the performance effects of the introduction of a wide portfolio of practices in a wide sample of 500 European firms, finding that the wider and more differentiated the set of practices introduced, the better. Practices are distinguished as pertaining to firm boundaries, structures or processes (hence, not as they are different in kind or logic, but as they invest different aspects of organization). Still, results support the contention that organizational changes realized through a set of practices encompassing different classes have affected firm performance more positively. The design implication would be that, for example, adopting together outsourcing (a boundary spanning practice), delayering (a structural practice) and teamwork (a process practice), should be better than, say, restructuring by delayering, horizontal integration and decentralization (a set of practices all of the structural kind). Even more pertinent to our purposes, researches on effective combinations of HRM practices have consistently shown that the most successful innovative organizations employ things as different as strongly powered incentives and teamwork together (Laurse and Manke 2001; Ichniowski et al., 1997).

Hence, there are both theoretical and empirical reasons to doubt that effective organizational combinations can be generated by a simple monotonic combinatory rule such as 'the more similar elements are, the better'. At the same time, the opposite simple combinatory rule, i.e. 'the more varied the combination of elements, the better', is also doubtful: isn't there any ceiling to the effective adoption of practices of different kinds? Can't complementarities vary in sign (e.g. from positive to negative) depending on the intensity of adoption? Are complementarities ubiquitous among all elements or limited to only some of them? Under what conditions?

All those questions led us to integrate the two simple laws mentioned above (and some others) into a more sophisticated set of combinatory laws, presented and justified below, together with some testable propositions derived from the laws, which are corroborated in the empirical study. These laws are also much more precise than the available propositions on the relation between the variety of practices and the overall system performance. In fact, the proposed combinatory laws specify what types of elements, and at which level of intensity, are necessary and/or sufficient to generate what type of performance.

'Law of organizational core variety'. The presence of elements of different kinds is a necessary condition for an organizational formula achieving high performance of any sort.

As it occurs in living natural systems, elements of different kinds (say iron or carbon), are typically needed at some basic normal level for combining in molecules performing basic functions, hence, also for delivering high performance of any kind. In artificial organizational systems, we can conjecture that a combination of incentives, formal rules of the game, right of appeal and sense of belonging, each present at some basic level different from zero, is necessary for the system to be able to function and deliver high performance of any kind. According to this hypothesis, organizational formulas should always include a 'core' in which all elements are present.
This 'law of core variety' of organizational formulas can be operationalized in the following testable necessary condition for high performance:

Proposition I. High performing combinations of practices should necessarily include at least one dose of each kind of element. The absence of any element is a sufficient condition for not observing high performance of any sort.

As in natural systems, some dose of, say, iron in the blood is needed, but raising the presence of iron to unspecified levels is unhealthy. The adoption of many practices, all carriers of one type of element, raises the intensity of the presence of that type of element in the system. For example, if a firm introduces pay for performance, stock options, profit sharing, tournaments for positions, and high personnel mobility and turnover, the presence of market-like elements will increase with the number of practices of the same kind adopted. The benefits from increased pressure on results decrease due to limits in the possibilities of increasing efforts and finding new performance increasing actions (Milgrom and Roberts 1992). In addition behavior is likely to become dysfunctionally competitive: all unrewarded tasks are likely to be neglected (Roberts 2004); costs and negative consequences not directly borne are going to be disregarded (Windolf 2004), and extrinsic motivation is going to 'crowd out' intrinsic motivation (Osterloh et al. 2001).

This 'law of decreasing marginal returns' to investments in organizational practices infusing elements of the same kind, just illustrated for market-like infusions, is known to be valid for all the other elements as well, although usually not expressed in these terms.

For example, to establish some rules and plans in a hypothetical 'spontaneous order' is likely to be generally necessary for achieving better outcomes; but keeping adding procedures and controls to solve any problem quickly entails larger costs than additional benefits, as the conspicuous critical literature on bureaucracy demonstrated (from Merton on). Analogously, some social cohesion is obviously valuable and efficient, but increasing investments in 'common culture', easily generate pathologies of 'oversocialization' and 'groupthink' (Janis 1972). Finally, although the use of democracy is by no means common in firms, there have been well known experiments in the infusion of democracy, even in large incorporated firms, such as, in the past at Volvo or Olivetti, or more recently and in higher doses, at Oticon and Semco. The Oticon case has been analyzed in some depth, and, according to our hypothesis, it has been documented that its reorganization, characterized by a rather full dismantling of bureaucratic practices and a rather intense infusion of democratic elements (Verona and Ravasi 2000); eventually ran into problems due to lack of incentives and rules (Foss 2003). Hence we state the following second combinatory law:

'Law of decreasing marginal returns to organizational homogeneity'. There are decreasing marginal returns, and, beyond some point, negative returns, to increases in the intensity of the same kind of element.

Decreasing marginal returns to investments in practices infusing elements of the same type, therefore, should set a ceiling to the intensity of effective presence of each single element. But other forces are likely to limit the breadth of effective organizational formulas too. If in low doses different elements complement each other, at higher doses there are reasons to hypothesize that they may entail negative complementarities ('dysinergies' rather than synergies). In fact, people energy, cognitive capacity and behavioral flexibility is limited; hence, they are unlikely to be able to attend and respond simultaneously to strong incentives; to strong demands for identification; to intense requirements for rule following and the use of procedures; and to the right and duty to exert their best judgment; being highly entrepreneurial, highly solidaristic, highly compliant, and highly informed critical participating citizens at the same time. In addition, practices are costly, and choice among alternative investments in different practices may become an issue as the total amount of investment increases.

If the above is true, then the following two further laws and third testable necessary condition to be met by high performing organizational formulas can be stated:

'Law of decreasing marginal returns to organizational variety'. There are decreasing marginal returns, and beyond some point, negative returns, to simultaneous increases in the intensity of all kinds of elements.

Both laws of decreasing marginal returns should lead to 'forbidding' the possibility of observing organizational formulas with one or more elements at maximum level in association with high performance. Hence, an empirical regularity, and testable proposition, deriving from those laws should be that a sufficient condition for observing low performance is the violation of the law, and a necessary condition for success is the respect of the law.

Proposition II. High performing combinations of practices should not be characterized by very high intensities of any element. The presence of any element in very high doses should be sufficient for not observing high performance of any sort.

The laws identified so far settle upper and lower bounds to the effective intensity of presence of elements in organizational formulas. Can we specify some further law predicting and prescribing which combinations to adopt, within those limits, in order to achieve specific outcomes?
Different elements infuse different principles of behaviour, hence the differential investment in one or the other (within the specified healthy ranges) can give a dominant orientation to the organization that may be more or less suitable for reaching different types of outcomes. The selection and pursuit of different performance parameters should generate complementarities among different sub-sets of elements that fit best to produce those outcomes. Hence, the type of outcome sought (and eventually other contingencies to be met) should be relevant for the choice of the element(s) in which to invest beyond the basic level (and below extreme levels). The relative weight of the different elements, between a basic level at which they are all necessary, and a very high level at which they are all dysfunctional, is what can characterize and distinguish a contingently effective organizational formula from another. Hence we state:

'Law of structural heterogeneity'. The optimal intensity of each element in an organizational formula (within the lower and upper bounds) is contingent to the type of performance outcome generated.

Proposition III. High performing combinations of practices should have the following structure: a *'core' in which all kinds of elements are represented at a basic level; and a 'belt' in which different* kinds of elements are represented in higher doses, depending on the types of performances outcomes produced.

Can we specify to some extent how the belt should be composed contingently to different outcomes to be produced? On the basis of available theory, and within the scope of the evidence that can be provided by the empirical study presented in this paper, we can advance two initial hypotheses on the composition of the 'belt' of organizational formulas.

A leitmotiv in organization theory is that organization forms effective in innovation and exploration are different from those effective in efficiency and exploitation. As far as internal organization is concerned, bureaucratic organization has always been supposed to have a prominent capacity in achieving efficiency in exploiting existing knowledge and resources (Mintzberg 1979; Burns and Stalker 1961).

By contrast, in the management of innovation, e.g. in organizing under high uncertainty, different contributions have alternately pointed out the virtues of investments and infusions into firms of all the other three classes of elements: either market infusions and incentive-driven organizing (Zenger and Hesterly 1997**),** communitarian governance (Ouchi 1979) and/or organizational democracy (Harrison and Freeman 2004). These different accounts, and indeed the observable differences among the structuring of highly innovative firms, raise some questions of what's behind this 'structural heterogeneity': are incentive driven and communitarian/democratic arrangements alternative and fungible solutions in the generation of innovative behaviors (Roberts 2004)? Or, rather, would combinations among highly powered incentives and team-like organization generate even superior innovation performance, revealing that investments in those two elements are in fact complementary in the generation of innovation (Laursen and Manke 2001)? The empirical study presented in the remainder of the paper will shed some light on the problem of structural heterogeneity in the governance of innovation.

Proposition IVa. *Highly efficient combinations of practices should be composed of a 'core' in which all elements are present, and a 'belt' of additional bureaucratic elements.*

Proposition IVb. Highly innovative combinations of practices should be *composed of a 'core' in which all elements are present and a 'belt' of communitarian, and /or democratic and/or market-*like additional elements.

From Organization Forms to Organizational Formulas: A Survey

We illustrate how the approach can be applied and tested by the exploratory study reported in this section. In order to identify and analyze empirically whether the types of elements combine as predicted, we conducted a survey on a medium-sized sample of firms.

Data Collection

We conducted a survey on the population of the largest 600 independent firms by revenue and with more than 150 employees operating in Italy in the year 2004. We distributed to the chief human resources officers of these firms a questionnaire on organizational structures and practices, initially tested in a pilot study and in several interviews with more than 40 human resource managers and directors. The total number of respondent firms was 90 -with an overall response rate of 15%, comparable to other recent European surveys (Whittington et al. 1999). 15 out of the 90 questionnaires collected were eliminated from the final sample for data unreliability due to the presence of missing data. Thus, our final sample involves 75 firms.

Measures

We designed the survey questionnaire following the table of correspondence between types of elements and observable practices introduced in Table 1 above. Data on the use of important contemporary practices for each element were gathered (for example, market-like type of elements has been identified by the following organizational practices: 'individual and team-based pay for performance', 'firm-based pay for performance', 'outsourcing', 'internal labor market mobility').

The intensity of adoption of each organizational practice was measured in two ways. For each organizational practice we identified a set of four more observable and operational sub-practices (e.g. for the organizational practice 'pay for firm performance' the list of sub-practices included: gain sharing, profit sharing, stock options, employee shareholding). The intensity of adoption of the organizational practice was measured in two steps: first, the number of sub-practices adopted by the firm was counted, generating a 0 to 4 scale; second, this indicator was dichotomized into a dummy variable, coded as '1' if the value of the indicator was equal or higher than the average value in the sample.

There are however a few practices, such as turnover, whose intensity of use is commonly measured in firms on percentage scales. In those few cases percentage scales were used as a starting measure (e.g. the practice "Internal Labor Mobility" was measured as the number of job-reassignments over the number of employees). These scales were in any case also dichotomized into a dummy variable, coded as '1' if the percentage value of the scale was equal or higher than the average value in the sample. Hence, in the end, we have homogeneous indicators of the intensity of use for all practices.[2] In addition, we also have a homogeneous measure of the number of 'doses' of an element (operationalizing the idea of the number of atoms of an element): one dose is infused if the practice is used at least at average (i.e. normal) level.

Given that we considered four practices for each element (see examples of practices in table 1), the intensity of use of any element can then range, potentially, from 0 to 4 in this study. We considered value 4 as 'high intensity' (the notion of 'high intensity' is relevant for testing Proposition II). This is justified as follows. First, we considered the maximum average intensity of application across all the four elements, and added the positive variance above it. This value is 3,57. Hence, in our sample, an intensity of 4 can indeed be considered very high. At the same time, there are in the sample enough cases in which value 4 appears for testing the effects of 'high doses' on performance. Second, the questionnaire contained open questions giving respondents the opportunity to indicate the adoption of other practices beside the four explicitly identified for each element. No respondent in the entire sample indicated other practices. This evidence is a further indirect confirmation of the reliability of the above operationalization of 4 practices as 'very high intensity" of an element[3].

As to organizational outcomes, in order to test our propositions, we considered two qualitatively different types of outcomes: efficiency and innovation. They were measured independently integrating different database sources (Bankscope, Eurostat, Amadeus, Aida), in order to avoid self-report biases. However, this concern forced us to use proxy indicators for which those data were available. Efficiency was measured by the revenue per employee of the firm in the year 2005 divided by the average level of revenue per employee of the firms operating in the same industry (identified by the SIC-CODE) in the same year. Innovation was measured as the number of trademarks deposited by the firm in the year 2005 divided by the average number of trademarks deposited by the firms operating in the same industry (identified by the SIC-CODE) in the same year. These ratio scales were dichotomized into dummy variables (1/0), coding each variable as 1 if above the average value of the ratio in the sample, and as 0 otherwise. Performance was measured with reference to 2005 to allow a one-year time lag between organizational arrangement (as adopted in 2004) and performance, as contingency studies' methodology suggests (Donaldson, 2001).

[2] A more refined measurement could have also considered the percentage of employees touched by the practice. Unfortunately respondents were unable to provide this type of data reliably.

[3] In other contexts, the number of practices representing 'high intensity' may be different.

Data Analysis Method and Findings

The choice of the data analysis method was driven by the need for detecting interaction effects among the four types of elements, the possible equifinality of different combinations for reaching the same outcome, and the possible redundancy of elements for outcome generation.

Standard methods -such as linear regression analysis and multivariate techniques as factor and cluster analysis are not able to adequately take into account all these factors. Although interaction effects have enriched standard linear regression to assess non-linear relationships, they nevertheless estimate the fitness of a single path to an outcome. Thus, they are in explicit contrast with the concept of equifinality (Fiss 2007). Furthermore, three-way interactions currently represent a limit for regression analysis applications – and concerns about their interpretation and reliability persist (Drazin and Van de Ven 1985; Ganzach 1998). Finally, cluster and factor analytic methods are unable to distinguish which independent variables are necessary, sufficient or redundant in affecting the dependent variable.

For these reasons, we decided to turn to new methods able to overcome these limits. In particular, we found Boolean comparative analysis (Ragin 1987; 2000) the most suitable for our purposes. In fact, this is, by design, a methodology and a technique for detecting the combinations of elements that are necessary and sufficient for obtaining a specified outcome (Braumoeller and Goertz 2000; Fiss 2007). The methodological passages necessary to understand the study are exposed together with the findings of the data analysis[4].

Formalizing Data into Organizational Formulas through Boolean Algebra

Combinations of elements can be expressed in the Boolean algebra language and its operators in the following way. Suppose a firm is adopting three market-like elements, two bureaucratic, one communitarian and one democratic element, and that it is classified as high performing in efficiency. This case can be formalized as follows:

$$M_3*B_2*C_1*D_1 \text{ ---> EFFICIENCY}$$

where "*" denotes the Boolean operator "AND", ---> denotes the logical implication operator and the number qualifying each capital letter (M = Market-like; B = Bureaucratic; C = Communitarian; D = Democratic) represents the number of doses (practices employed beyond the average level)

4 For further understanding the basic concepts and procedures employed in Boolean Comparative Analysis (BCA), we refer the interested reader to the short illustration provided on the topic in the appendix posted on the authors' website www.crora.unibocconi.it (Homepage > English site > A chemistry of organization appendix). Fs/QCA, the software used for the analysis, and more information on the methodology are available on the website www.fsqca.com.

employed for each of the four types of elements. The above statement can be read as "The combination of three doses of market AND two of bureaucracy AND one of community AND one of democracy can be observed in association with a high efficiency outcome".

Let's now suppose that in our sample there is another firm that adopts a different formula and also achieves high efficiency, such as $M_1*B_3*C_2*D_2$. The presence of these two firms in our sample can be formalized through the Boolean operator “OR” (+):

$$M_3*B_2*C_1*D_1 + M_1*B_3*C_2*D_2 \dashrightarrow \text{EFFICIENCY}$$

where "+" denotes the logical operator "OR". The above statement can be read as: “A high efficiency outcome can be observed in association with the combination of three market-like AND two bureaucratic AND one communitarian AND one democratic doses; OR in association with the combination of one market-like AND three bureaucratic AND two communitarian AND two democratic doses of elements.

Thus, when used on sufficiently large sets of possible combinations, the "OR" operator expresses substitutability (or equifinality), while the ‘AND’ operator expresses relations of simultaneous necessity or complementarity.

Using these notations, we formalized our dataset into a set of organizational formulas and explored their association with high performance on efficiency and innovation.[5]

Testing Proposition I and II

The second step of the analysis should answer the question: are there combinatory patterns common to the equifinal combinations associated to the same type of outcome? Do they conform to the propositions derived from the combinatory laws hypothesized?

Our propositions can be best tested distinguishing between necessary and sufficient conditions (Ragin 1987). Expressed more operationally:

- Proposition I states that the presence of all four elements at some level different from zero should be a necessary (albeit not sufficient) condition for observing a positive outcome (high performance in our study) on any performance parameter (efficiency and innovation in our study);

[5] The tables summarizing all the organizational formulas detected in the sample are provided in the Appendix posted on the authors’ website www.crora.unibocconi.it.

- Proposition II states that the presence of any element at very high level (level 4 in our study) should be a sufficient (albeit not necessary) condition for observing negative outcomes on all performance parameter (no high performance on any parameter).

Then , we further operationalized the combinatory rules constructing a dummy variable –labeled "ALLTYPES_1or2or3"- that was coded as "1" if all the four types of elements are used in a combination, each with a number of practices greater than 0 and lower than 4; it was coded as "0" otherwise. According to our hypotheses, we expect the positive values of the variable to constitute a necessary condition to achieve positive organizational outcomes, whereas the negative values to be a sufficient condition for negative outcomes. A condition is said to be necessary if the outcome can be observed if and only if the condition is present, and is said to be sufficient if the presence of the condition implies the presence of the outcome. Expressed this way, the notions are deterministic. However, it is possible to express them in a probabilistic way, more compatible with an empirical test (it would be almost impossible to satisfy these rules with probability one, i.e. in 100% of the cases). A threshold of frequency lower than 100% can be fixed expressing this notion of 'statistically necessary' and 'statistically sufficient'. A threshold usually employed in Boolean Comparative Analysis studies is 65% (Ragin 2000: 109), so we adopted this heuristic.

The actual proportion of cases conforming to our rules is in any case usually much higher (80-90%). The results of the necessity and sufficiency tests[6] are reported in tables 2 and 3 below.

TABLE 2 AND 3 ABOUT HERE

The results are clear-cut in confirming the core combinatory rules hypothesized, and interesting in the refinements they suggest. They read as follows:

- The respect of the combinatory rule 'all types of elements should be present, with values comprised between a lower and an upper bound' (operationalized as 1 and 3 in this study) is a **necessary and sufficient** condition for high **efficiency**. Any violation of this rule (e.g. the use of zero or four elements per type) is a **necessary and sufficient** condition for lower efficiency.
- The respect of the combinatory rule 'all types of elements should be present with values between a lower and an upper bound' (operationalized as 1 and 3 in this study) is a **necessary** but not sufficient condition for high **innovation**. Any violation of this rule is a **sufficient** but not necessary condition for lower **innovation.**

[6] For a detailed understanding of the necessary and sufficiency tests employed in the analysis we refer the interested reader to Ragin (2000: 109-119).

- If we consider a joint outcome function, i.e. achieving **both efficiency and innovation**, of course the more restrictive among the conditions for each outcome determines the law for the joint outcome: the respect of the combinatory rule 'all types of elements should be present with values between a lower and an upper bound' (operationalized as 1 and 3 in this study)' is a **necessary** but not sufficient condition for achieving both high efficiency and high innovation (as for innovation only). Any violation of this rule is a **necessary and sufficient** condition for not achieving both outcomes (as for efficiency only).

In other terms, the results indicate that any violation of either the law of organizational core variety or the laws of decreasing marginal returns to organizational homogeneity and heterogeneity is a necessary and sufficient condition for ending up with relative inefficiency. For innovation, respect of the rule is a necessary condition, but, even if respected, the high innovation outcome may not occur. This is an interesting and sensible asymmetry between organizing for efficiency and for innovation: as innovation is uncertain by definition, the link between organizational solutions and the outcome is weaker than for efficiency.

Testing Proposition III and IV

The analyses presented here inquire into the composition of effective organizational formulas within the lower- and upper- bounds specified by the core combinatory laws tested above. Operationally, the hypotheses we developed in that respect lead to expect the following:

- Proposition III predicts that the 'belt' of organizational formulas, beyond the core, should be composed of different elements depending on the type of outcome.
- Proposition IVa and IVb specify that bureaucratic elements should prevail in the belt of efficient formulas, while the other three elements should prevail in the belt of innovative formulas.

To test these propositions, we first constructed two dummy variables for each element: LOW (1 dose of the element is present), MED (2 or 3 doses are present).

The expectation is that we should observe levels of bureaucracy beyond the base rate (hence at level 2 or 3) in 'efficient' formulas; while in 'innovative' formulas we should observe those higher levels in the other three elements. The results of the analyses of necessary and sufficient conditions, separately conducted for the three levels of presence of each element, are reported separately for efficiency, innovation, and both efficiency and innovation, in tables 4, 5, 6, respectively.

TABLE 4, 5, 6 ABOUT HERE

As predicted by Propositions III, VIa and VIb, operationalizing the law of structural heterogeneity, the rules of composition of organizational formulas beyond the core, are qualitatively different for the two types of outcomes: for efficiency, additional doses of bureaucracy are necessary; for innovation, additional doses of **either or both community and market elements** are necessary (Tables 4 and 5). The necessary conditions for getting both results are a union of those separate conditions, hence additional doses of **all three elements**, bureaucratic, communitarian and market-like are necessary (Table 6).

Results indicate that as the result parameters broaden, the number of necessary elements and the necessary internal variety of the organizational formula increase. Results also suggest that negative complementarities among three types of elements, traditionally considered to be ‘inconsistent’ (because of their difference in kind), do not actually arise even at sustained levels of use (level 3). They might arise at very high levels (level 4), but at those levels even the use of ‘consistent’ (similar in kind) elements is not healthy.

Finally, our empirical evidence suggests that ‘incentive-driven organization’ and ‘communitarian organization’ are neither mutually exclusive structural alternatives nor strictly complementary in the governance of innovation. Elements of market and community seem to behave more like fungible substitutes, as (the belt of) organizational formulas generating high innovation can be composed by either elements of market, or of community, or of both without the outcome being altered. This fungibility in sustaining innovation seems to apply to some extent also to the use of democratic elements: the results are in the predicted direction although the test is not strictly significant (0.519).

Discussion and Conclusion

A chemistry of organization, whose foundations have been laid down in this paper, provides two much needed ingredients for a ‘science of design’ intended as a set of rules capable of generating organizational configurations: what the fundamental organizational elements to be combined are, and which the combinatory rules for generating specified outcomes are. We have shown that some general, invariant, laws can be specified and that high performing organizational formulas seem to obey to them, in spite of and beyond their variety. This approach focuses on the scientific part of design, namely on the basic chemical laws that any design should respect, even though the full specification of organizational solutions cannot but involve the application of other criteria as well, including aesthetics or politics. The very understanding of the ‘technical’ laws not to be violated should actually enable more healthy and creative application of artistic or political criteria. A chemistry of organization, as initially operationalized and tested in this study, already provides precise and strong rules for organization design, which can be summarized as follows.

- Effectively designed systems, both for efficiency and for innovation, should be composed of organizational attributes of different kinds, rather than of all attributes of the same kind;
- The more varied the type of outcome sought, the more varied the organizational elements to be infused;
- There is asymmetry between designing organization for efficiency and for innovation: as innovation is uncertain by definition, following design rules is a necessary but not sufficient condition for high innovation; while it is possible to identify necessary and sufficient conditions for high efficiency. Organizational formulas capable of generating high efficiency are enriched in bureaucracy, while those generating high innovation are enriched in market-like or communitarian elements (or both).

Our study is the first in its kind. Therefore, it can be extended and refined in a variety of ways, such as the following:

- The empirical data analyzed here are limited in time and space. They provide an explorative and illustrative analysis, but more extensive testing would naturally be important.
- The 'table of elements' can be refined by further breaking down the types of elements into more micro elements (e.g. prices, rules, teams, etc.).
- This paper has considered the link between organizational elements and types of outcomes. A possible straightforward extension of this type of analysis would be to consider some other relevant elements that are likely to interact with organizational elements. The characteristics of technology, tasks and resources are obvious candidates. These variables can be plugged into Boolean analytic terms as further types of elements to explore necessary and sufficient associations with organizational elements.
- At a more general, modeling level, we should observe that the model developed here is static. Although a good statics is a necessary initial step for developing any good dynamics, it would indeed be desirable and interesting to understand how the combinations can change. The specification of whether any element, or package of elements, is necessary or sufficient, and which elements are substitutable, provide a starting basis for developing dynamic models. On these grounds it contributes in refining the rough hypothesis that has been

typically derived from complementarity-based analysis: namely, that 'the wider the package of practices that are changed together, the better' (Whittington et al 1999). This may be a sensible strategy only if it is not known where the complementarities lie. Knowing the chemistry of combinations would allow devising partial, more targeted, less costly changes.

In conclusion, two general implications of a chemistry of organization for the future direction of organization theory as a science of design can be highlighted. First, it provides a basis for enriching the available theories of 'structural contingency' with a theory of 'structural heterogeneity'. Second, by going beyond the traditional archetypical, frequency-based, discrete notion of 'organization form', a chemistry of organization provides a basis for devising new possible configurations, thereby reconnecting to Herbert Simon' notion of design as a science of the artificial concerned with the 'world as it might be'.

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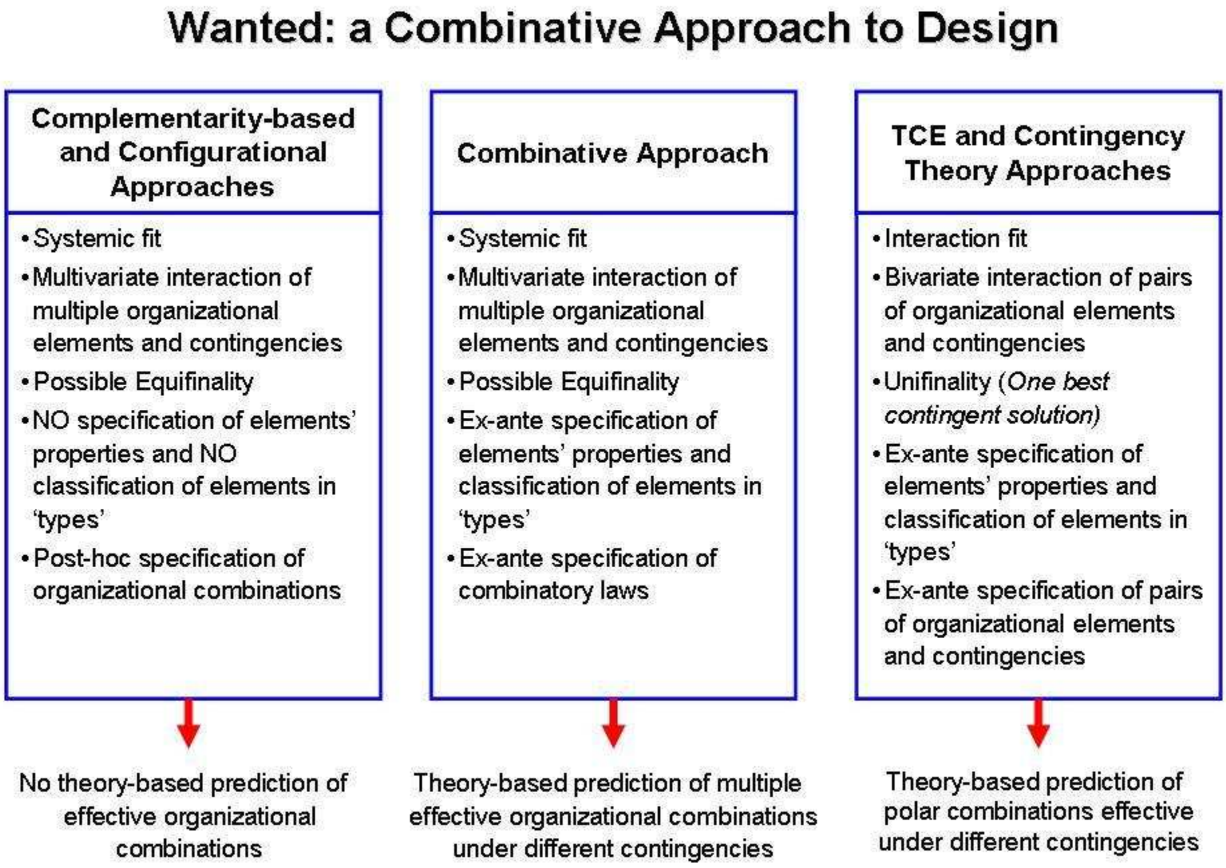

Figure 1 - The Need for a Combinative Approach to Design

Table 1 – Organizational Elements, Principles of Behavior and Practices

Types of organizational elements (Classes of pure chemical elements)	Principles of behavior infused into the organization by the element (Active principles infused into the organism)	Practices predominantly embodying the element (Drugs)	References
Market-like Elements Price-like and Control-by-exit devices	Infusing highly powered incentives and capacity of coordinating action with minimal communication	❑ Pay for performance (individual and team-based) ❑ Pay for performance (firm-based) ❑ Outsourcing ❑ Internal labor mobility	Von Hayek 1945 Hirschman 1970 Williamson 1975; 1993 Zenger and Hesterly 1997
Bureaucratic Elements Formal rules and plans; Specialized division of labor	Infusing predictability, transparency and accountability	❑ Formal Evaluation System ❑ Formal rules, procedures and programs ❑ Articulation of formal structure ❑ BPR and process organization	Gouldner 1954 Blau and Scott 1962 Pugh et al 1969
Communitarian Elements Knowledge and value sharing, common culture	Infusing identity and cohesion, homogenizing judgments and interests	❑ Knowledge sharing practices ❑ Community building policies ❑ Teamwork ❑ Project-based self-organization	Hofstede 1980 Ouchi 1980 Kogut and Zander 1996
Democratic Elements Allocation of ownership, decision and representation rights	Infusing voice and fairness, integrating different judgments and interests	❑ Job enrichment and empowerment ❑ Diffusion of ownership ❑ Diffusion of decision and reward rights to units ❑ Diffusion of representation rights	Gouldner 1954 Lammers and Szell 1989 Blair 1995 Harrison and Freeman 2004

Table 2 – Necessary and Sufficient Conditions for High Efficiency and Innovation
(Condition tested: All the elements are used with a number of practices greater than 0 and lower than 4)

	Necessary Conditions					Sufficient Conditions
Outcome tested	Condition[7]	N	Observed proportion	Z	p	
High Efficiency (N=37)	alltypes_1or2or3	4	0.11			Sufficient Condition:
	ALLTYPES_1or2or3	**33**	**0.89**	**2.91**	**0.002***	**ALLTYPES_1or2or3**
High Innovation (N=18)	alltypes_1or2or3	1	0.06			Sufficient Condition:
	ALLTYPES_1or2or3	**17**	**0.94**		**0.005***	**No Sufficient Cause Found**
High Efficiency and Innovation (N=11)	alltypes_1or2or3	0	0.00			Sufficient Condition:
	ALLTYPES_1or2or3	**11**	**1.00**		**0.009***	**No Sufficient Cause Found**

Test Proportion: 0.65, p< 0.05 — Test Proportion: 0.65, p< 0.05

[7] Capital letters indicate the presence of the condition; non-capital letters indicate the absence of the condition.

Table 3 - Necessary and Sufficient Conditions for Absence of High Efficiency and Innovation
(Condition tested: All the elements are used with a number of practices greater than 0 and lower than 4)

	Necessary Conditions					Sufficient Conditions
Outcome tested	Condition[8]	N	Observed proportion	Z	P	
Not-Efficiency (N=41)	**alltypes_1or2or3**	**34**	**0.83**	**2.24**	**0.012***	Sufficient Condition: **alltypes_1or2or3**
	ALLTYPES_1or2or3	7	0.17			
Not-Innovation (N=60)	alltypes_1or2or3	37	0.62			Sufficient Condition **alltypes_1or2or3**
	ALLTYPES_1or2or3	23	0.38			
Not-efficiency and Not-Innovation (N=34)	**alltypes_1or2or3**	**33**	**0.97**	**3.74**	**0.000***	Sufficient Condition: **alltypes_1or2or3**
	ALLTYPES_1or2or3	1	0.03			
	Test Proportion: 0.65, p< 0.05					Test Proportion: 0.65, p< 0.05

[8] Capital letters indicate the presence of the condition; non-capital letters indicate the absence of the condition.

Table 4 - Necessary Cause Analysis for High Efficiency

Variable	N	Observed proportion	Z	P
Lowmkt	29	0.78	0.28	0.388
LOWMKT	8	0.22		
Lowbur	34	0.92	2.18	0.015*
LOWBUR	3	0.08		
Lowcom	25	0.68		
LOWCOM	12	0.32		
Lowdem	29	0.78	0.28	0.388
LOWDEM	8	0.22		
Medmkt	9	0.24		
MEDMKT	28	0.76	-0.09	0.462
Medbur	5	0.14		
MEDBUR	32	0.86	1.42	0.077
Medcom	13	0.35		
MEDCOM	24	0.65		
Meddem	11	0.30		
MEDDEM	26	0.70		

Number of Cases Tested (Outcome>0): 37 (47.4% of Total).

Test Proportion: 0.75

Significance Level: *p < 0.05

Table 5 – Necessary Cause Analysis for High Innovation

Variable	N	Observed proportion	Binomial P
Lowmkt	18	1.00	0.006*
LOWMKT	0	0.00	
Lowbur	16	0.89	0.135
LOWBUR	2	0.11	
Lowcom	18	1.00	0.006*
LOWCOM	0	0.00	
Lowdem	15	0.83	0.306
LOWDEM	3	0.17	
medmkt	1	0.06	
MEDMKT	17	0.94	0.039*
medbur	2	0.11	
MEDBUR	16	0.89	0.135
medcom	0	0.00	
MEDCOM	18	1.00	0.006*
meddem	4	0.22	
MEDDEM	14	0.78	0.519

Number of Cases Tested (Outcome>0): 18 (23.1% of Total).

Test Proportion: 0.75

Significance Level: *$p < 0.05$

Table 6 - Necessary Cause Analysis for BOTH High Efficiency and High Innovation

Variable	N	Observed proportion	Binomial P
Lowmkt	11	1.00	0.042*
LOWMKT	0	0.00	
Lowbur	10	0.91	0.197
LOWBUR	1	0.09	
Lowcom	11	1.00	0.042*
LOWCOM	0	0.00	
Lowdem	8	0.73	
LOWDEM	3	0.27	
Medmkt	1	0.09	
MEDMKT	10	0.91	0.197
Medbur	1	0.09	
MEDBUR	10	0.91	0.197
Medcom	0	0.00	
MEDCOM	11	1.00	0.042*
Meddem	4	0.36	
MEDDEM	7	0.64	

Number of Cases Tested (Outcome>0): 11 (14.1% of Total).

Test Proportion: 0.75

Significance Level: *p < 0.05

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