Indexing Industry Modularity using Direct Requirements Tables: A Quantitative Definition

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Abstract

Modularity is a concept that has attracted attention as a strategy for reducing costs and increasing efficiencies in production processes. Despite the substantial potential benefits, the previous literature has settled on neither a qualitative definition nor a quantitative measure of modularity. We begin by reviewing previous definitions and cost-reduction roles of modularity both in theory and in actual production process case studies. Based on the roles in the literature base and the dimensionality of the Bureau of Economic Analysis's 2007 Commodity-by-Industry Direct Requirements Input-Output table , we identify and define a set of variables that characterize the production processes of industries previously identified in the literature as having modular production. We select a sample of industries having these characteristics and denote them as "modular." We select a second sample of industries which have little or no potential for modular production and denote them as "non-modular." We assign values of 1 to the denoted modular industries and values of 0 to the denoted non-modular industries. We use binary probit regression analysis with the explanatory variables being those that characterize the production processes of modular industries to develop a model to predict modularity potential based on the values for the variables. This model has a very good ability to separate modular from non-modular industries within the sample and is robust to reasonable variations in assumptions. We apply the model to the remaining out-of-sample industries to obtain their modularity index values and analyze the results. We propose that those industries with higher index values are candidates for incorporating modularity in their production processes and suggest that adopting such processes may lead to cost reductions for firms in those industries in the context of managerial and real world applications.

I. Introduction

For such a widely discussed concept, there is a relatively thin base of academic literature on the subject of modularity. However, there is much to be said about modularity in industrial organization in the context of other fundamental economic theories. The literature applies these concepts to the construction of modular systems theory, but previous works do not seem to have reached a conclusion regarding how to define modularity (Gershenson, et al., 2003). We do not attempt to provide a universal definition for modularity either, but instead we articulate a descriptive and quantitative methodology to define the concept of modularity at the industry level. We begin with a review of how modularity is understood in theory, production, and cost-reduction applications. We then identify measurable firm characteristics associated with modularity at the industry level. Next we construct an index of modularity based on firm characteristics within a sample of industries known a priori to be modular or not. We apply our index to industries not previously identified as being modular to find potentially modular industries. We conclude with a discussion of results and suggest applications of the findings.

II. Understanding Modularity

I. Modularity in Theory

The global economy today is an incredibly complex system, from the mechanical production process, to the global financial system, to governmental and regulatory bodies and social systems. All of these systems operate independent of each other and are yet interdependent and interconnected. Each trade relationship, national economic system, central bank, firm, and individual household is an independent system operating in the context of many larger systems. The global financial crisis of 2007 and 2008 demonstrated this contextual and interdependent relationship quite clearly. Herbert Simon describes these complex systems as "made up of a large number of parts that have many interactions. . . in such systems, the whole is more than the sum of the parts, in the weak but important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole" (Simon, 19, 2003). Organizational complexity is, then, a function of the number of parts in a whole as well as the "nature of their interactions" (Simon, 19, 2003).

A fundamental way to manage complexity in a large system is to group the elements of a system into a smaller number of sub-systems, as is often seen in nature. Simon's seminal work focused on the decomposability of systems, the concept of reorganizing a complex system into subsystems that can function at a basic level independent of the larger system. Simon offers a parable in which two watchmakers, Tempus and Hora, are both frequently interrupted in their work. "Tempus organized his work in a manner that if he had one watch partly assembled and had to put it down. . . it immediately fell to pieces and had to be reassembled from the elements" (Simon, 19, 2003). Hora, on the other hand, built his watches with "stable subassemblies that could then be put together in a hierarchic fashion into larger stable subassemblies" (Simon, 19, 2003). When Hora was interrupted, he only had to resume from the most recent subassembly. Tempus faced what Simon termed "perpetual incompleteness" in his watchmaking process, while Hora's modular production process allowed him to separate the production, performance, and success of each subassembly from the others (Simon, 20, 2003). Giving Hora a significant advantage in the watchmaking process, "Modularity facilitates the retention and reuse of system parts and enhances the speed, scope, and reach of innovation" (Garud, Kumaraswamy, and Langlois, 2, 2003).

The concept of modularity in production processes has been analyzed in industries from Silicon Valley to Detroit. There has been a recent shift towards modular systems and even more towards modular products, as firms seek to increase cross-compatibility among products, reduce repair and installation costs, and increase large-scale production. As a general measurable concept, modularity is the degree to which components of a system can be separated and recombined. Modularity has also been defined qualitatively by economist Richard Langlois as a "set of principles for managing complexity" (Langlois, 19, 2002). Langlois (19, 2002) writes that, "By breaking up a complex system into discrete pieces—which can then communicate with one another only through standardized interfaces within a standardized architecture—one can eliminate what would otherwise be an unmanageable spaghetti tangle of systemic interconnections" (19, 2002). Likewise, Schilling and Steensma (2001) described modularity as "a situation where 'a tightly integrated hierarchy' is supplanted by 'loosely coupled' networks of organizational actors" (1149). However, modularity is, in essence, a process. Baldwin and Clark define modularity as the process of "building a complex product or process from smaller subsystems that can be designed independently yet function together as a whole" (2000, 84). Analyzing the laptop computer industry, they argued that modularity is a concept far more widely applicable than was realized in the academic world at the time of publication. Just about everything in the economy, to some degree, is modular, from physical products to the organizational structure of the firm to this article. The degree of modularity present is tied to the level of complexity, but the concept is nearly universal. Modularity is, then, the level of decomposability and intercommunication in a process or system observed as a function of its complexity.

Modularity is parallel with the concept of division of labor among components, where each subsystem operates individually as a part of the larger system, without a dependency or cost component to communicating across a system (Langlois, 2002). Applied to production, modular products are comprised of individual components sourced from different resource bases and produced in separate production processes. This facet of modular production allows components to be assembled separately and then combined in the final stage of production, increasing production efficiency and lowering costs. Modular production shapes industrial organization and supply chain dynamics. Firms that produce modular products often source intermediate modules from multiple points on the supply chain and simply guide final assembly. Similarly, Sanchez and Mahoney (1996) assert that "products design organizations." In other words, modular products require modular production and non-modular products require non-modular production (63). Modularity in industry organization is an indicator of its level of complexity, and increasing the degree of modularity in products and processes will yield efficiency increases and cost reductions.

According to Langlois (2002), clearly defined property rights are critical to creating modular systems. Citing the work of Adam Smith and Ronald Coase, Langlois asserts that property rights and ownership of decision-making rights can inherently modularize social and economic interaction. In fact, Langlois considers Adam Smith to be the first economist to suggest modular organization in production, based on his discussion of the division and specialization of labor and diminishing marginal productivity in The Wealth of Nations. Another early proponent of property rights is Armen Alchian, who defines a system of property rights as, "a method of assigning to particular individuals the authority to select, for specific goods, any use from a non-prohibited class of uses" (Alchian, 1973, p. 26). In other words, the authority to classify and organize economic activity to one's liking and net benefit is the ability to modularize a resource, good, or service, resulting in economic efficiency gains. Langlois agrees, arguing, "the creation of 'new' rights and the re-bundling of existing rights are really manifestations of the same underlying process of modularization, re-modularization, and sometimes even de-modularization"

(27, 2002). Ultimately, however, clear definition of property rights is most critical for internalizing externalities. Without clearly defined property rights, Garrett Hardin's Tragedy of the Commons is likely to occur in the resource extraction phase of the modularized production process (Hardin, 1245, 1968). These externalities are of course "subject to the costs of setting up and maintaining the rights as well as to other considerations, notably the presence of economies of scale" (Langlois, 28, 2002). However, firms often find themselves in a non-modular organizational structure within an economy, and therefore "arise as islands of non-modularity in a sea of modularity," creating more externalities (Langlois, 34, 2002).

Another common theme in the literature is the necessity of decomposability of systems as a pretext for modularity. Recall Simon's parable of the watchmakers, in which he offers decomposability as a necessary requirement for modularity. Simon (19, 2003) considers decomposability "a prescription for human designers and... a description of the systems we find ready-made in nature." Without decomposability, systems will be resigned to the impeded progress and "perpetual incompleteness" of Tempus's watchmaking procedures. Langlois also argues for decomposability as a criterion for modular systems. When systems are decomposable, he argues, they have heightened compatibility with similar systems, allowing the interchange of parts and components, as well as ease of repair and installation (22, 2002). On the other hand, in non-decomposable systems, the successful operation of any given part is likely to depend on the characteristics of many other parts throughout the system" (Langlois, 21, 2002). D.L. Parnas, a computer scientist who made some highly pertinent observations about programming that have since been applied more universally to the concept of modularity, argued that modular systems are not automatically decomposable, "since one can break the systems into modules whose internal workings remain highly interdependent with the internal workings of other modules" (Parnas, 1056, 1972). He argues that modules within systems ought to operate independently of the other modules, with limited information transfer. However, on the other hand, Langlois notes that decomposable systems inherently do poorly in identifying and correcting errors, because they are each contained in individualized systems. Non-decomposable systems raise the cost of missing or poorly functioning parts, which raises the incentive to make sure that each part is of high quality (24, 2002).

Another critical facet of modular systems is non-interdependence, meaning that sub-systems are functional and independent of each other as they function within a larger system. Especially in large modular systems, Parnas (1972) argues that the organizer's goal ought to be to minimize interdependencies and intercommunication among the modules. By doing so, transaction and communication costs are minimized and the systems maintain their independence. He argues that, although modular systems are difficult to design, by reducing interdependencies and therefore communication costs, firms can reap the benefits of specialization and the division of labor more easily (2002, 23). Using the Japanese auto industry as an example, he makes the point that non-decomposable modular systems stimulate learning-by-doing benefits because they "highlight bottlenecks and inconsistencies" and raise the incentive to produce higher quality components (2002, 24).

The literature reviewed above suggests that the division of labor, clearly-defined property rights, system decomposability, and non-interdependence are major components of modular systems theory.

II. Modularity in Production

Nearly every process is, to some degree, modular. However, especially in production, the inherent modularity of a firm's product will often point to an organizational structure of the firm that is also inherently modular. Sanchez and Mahoney (1996) content that products design organizations, not the other way around. This means that non-modular products lead to non-modular organizations, and modular products call for modular organizations. In a sense, however, this is a variant on what the mainstream economics of organization has long believed: that production processes design organizations (63). If this is true, then firms are in essence, non-interdependent confluences of modules of production processes, property rights, and ownership of decision-making rights.

Glen Hoetker argues that organizational modularity has multiple advantages for firms and that product modularity has a quantifiable, causal relationship to organizational modularity (2006, 513). Firms can outsource, reselect and switch suppliers, and engage in 'modular innovation,' in which "firms improve their end product by incorporating improvements in various components of the product, which may occur at different rates for different components," with ease (Hoetker, 2006, 502). After studying the notebook computer industry, Hoetker "provide[d] empirical evidence on the impact of product modularity on the ease with which a firm can reconfigure its own organizational design" (Hoetker, 2006, 513). This was in contrast to Baldwin and Clark, who argued that product modularity pushed firms away from hierarchal structures (2006, 88). Hoetker also establishes that modularity is not a "monolithic" concept, meaning that loosely coupled, configurable networks and moving out of hierarchy are separate phenomena and that "one can exist without the other" (Hoetker, 2006, 514). Schilling and Steensma (2001, 1149) described modularity as "a situation where 'a tightly integrated hierarchy' is supplanted by 'loosely coupled' networks of organizational actors." Hoetker disagrees, asserting that "loosely coupled, configurable networks and moving out of hierarchy are separate phenomena and that one can exist without the other" (Hoetker, 2006, 514). These arguments ultimately lead to the same end: that ultimately, modular outputs demand modular inputs, and that the trait of modularity is applicable among all stages of the production process, and that this property of modular systems can have huge efficiency benefits for firms.

Modularity is, as previously mentioned, a nearly universal concept. In this vein, firms are increasingly finding that transforming their organizational structures yields similar efficiency increases to those experienced in modular production. In its greater universality than originally thought, Baldwin and Clark argued "a growing number of industries are poised to extend modularity from the production process to the design stage" ('Baldwin and Clark, 2000, 85). In doing so, business planners and designers apply these concepts to firms' organization, achieving modularity by splitting it into its components (in a nearly modular fashion): visible design rules and hidden design parameters. The visible design rules consist of architecture to define module boundaries, interfaces that describe the intercommunication of the modules, and standards for measuring individual module performance. The hidden design parameters are decisions that do not affect the design beyond the local module and are not communicated to the modules in an organization (Baldwin and Clark, 2000, 88). In light of changing business environments and the trends toward modular organization, companies are shifting to become one of two types: either an architect of an organization with the motive to create products made up of modules or a designer of modules that conform to the architecture of other firms (Baldwin and Clark, 2000, 88). This observation has significant implications for vertical integration, production and supply chain analytics, and even questions of labor and employment.

III. Modularity as a Cost-reduction Strategy

It is evident that modular structures of organization come with large increases in efficiency for a firm. For example, Thyssen et al. (2006) show variable cost reduction benefits as a result of product-unique modules in production. Likewise, the modular structure gives full rein to the Smithian economic benefits of specialization, the division of labor, and marginal productivity of labor. Langlois and Robertson (1992) argue for demand side benefits and supply side benefits of modular organization. On the demand side, the largest benefit is the "ability to fine-tune the product to consumer needs and therefore blanket the product space more completely" (297). On the supply side, firms have the "potential for autonomous innovation, which is driven by the division of labor and provides the opportunity for rapid trial-and-error learning" (297). Langlois and Robertson (1992) suggest that innovation in modular systems can lead to "vertical and horizontal disintegration, as firms can often best appropriate the rents of innovation by opening their technology to an outside network of competing and cooperating firms" (298). They further assert that increasing consumer demand and the importance of achieving scale economies in production emphasizes the benefits of modular organization.

However, as economists famously say, there is no such thing as a free lunch. Baldwin and Clark (1997) note that modular systems are much more difficult to design than comparable interconnected systems, and that without a thorough knowledge of the inner workings of the production process, the modules will function poorly together as an integrated whole (86). In addition, redesigning an entire firm's structure can be costly, and maintaining independent modules often incurs a high communications cost (Langlois, 20, 2002). In many cases, the benefits of modularization may not be worth the cost, especially when the system is in an environment where adaptability is unnecessary (Langlois, 23, 2002). It is important to note that, just like any economic problem, rational societies (and the economic actors within them) will only willingly incur the cost of an action if it is exceeded by its benefit. Economist Yoram Barzel gives an analogy:

> Economists have been well aware that the modular design of property rights comes at a cost, and that societies (and the economic agents within them) will want to pay that cost only if it is worth the benefit. Restaurant owners do not assert their full property rights over the salt they offer customers, but instead place the salt "in the public domain." Even though this destroys the patron's incentive to husband salt, any inefficiencies are dwarfed by the transaction costs of monitoring and charging for the use of the salt (Barzel, 1989, 66).

However, notice that architectural innovation doesn't always imply a change in the firm's "visible design rules" (Sanchez and Mahoney, 1996, 65). For example, LEGOs and TinkerToys are classic examples of modular systems designed for architectural innovation (65). For those firms that have positive net benefits from investing in a modular structure, there are efficiency gains, management benefits, and lower costs in store for them. For the other types of industries where modular organization provides negative net benefits, firms will remain non-modular and non-decomposable.

Ultimately, firms that provide modular goods or services will become more modular in their internal organization, in the production process, and in their supply chain management. Firms that provide non-modular products or whose costs of changing the architecture are prohibitive will remain non-modular.

III. Towards a Quantifiable Modular Industry Theory

Our view is that modularity is among the characteristics that distinguish firms in one industry from those in another. Firms in each industry have a potential for modularity based on identifiable characteristics of those firms. We propose that the potential for modularity is an industry characteristic that can be expressed as an index which captures the probability of firms succeeding in becoming modular. We identify a set of firm characteristics that clearly separate industries that have already achieved modularity (and which therefore have a modularity probability of 1) from those that cannot be modularized (and therefore have a modularity probability of 0). We then use these characteristics to assess the potential for firms in industries that have not yet adopted modularity in their production processes to do so. We next identify important characteristics of firms in all modular industries.

Modular industries are generally focused on final assembly, rather than transformation of raw resources. Rather than being involved in first stage extraction or processing, modular firms source intermediate components or services from other firms and assemble them into final products. This assembly-based production process is generally more labor-intensive than capital-intensive. A classic example of this is the computer industry, in which firms like Apple, Dell and Hewlett-Packard assemble processors, LCD screens, track pads and hard drives, each of which is a module in and of itself, into modular laptop and desktop computer systems. These systems are modular because each of these components operates independently of other systems in the computer, yet within the larger context of the entire system. In contrast, non-modular firms, such as steel mills, paper mills, and food processing companies, are likely to have a high level of energy intensity, as these industries generally transform raw materials into first stage intermediate goods in their production processes and transformative production is often energy intensive. As a result, we expect that a modular industry will have a lower energy intensity, defined as energy use per dollar of output.

Technology-intensive products are often produced in modular processes. Langlois and Robertson (1991) show that the level of modularity and the level of technology used in an industry can be positively correlated. Further, Sanchez and Mahoney (1996) conclude that products, and therefore production processes, design and shape organizations. Because most example modular industries produce goods that utilize high levels of electronic technology, we expect that the modularity of an industry will be positively related to the level of technology.

Firms in modular industries often source intermediate components such as the modules they assemble from firms in other industries and "cross-border doordination with supply chain partners" leads to increased mass customization capability (Zhang et al., 2014). Thus we expect that modular firms will have greater inter-industry (supply chain) interactions than non-modular firms. This interaction can be measured by the proportion of the value of goods or services transacted between firms in the industry and those in all others, its inter-industry interactions.

In a similar vein, sourcing components from other firms in other industries is expected to be correlated with greater transportation and shipping costs. Buying intermediate components and input services from around the world based on resource availability, cost of labor, and existing infrastructure, many modular firms allocate a large portion of expenditures towards shipping and transportation costs in order to move the components to one place where they can be assembled into the complete product. Therefore we expect a firm's transportation cost to be positively correlated with its degree of modularity.

Lastly, this sourcing of intermediate components bears a cost. Because firms incur transaction costs, unit costs, and other types of costs by sourcing components from multiple other firms along the supply chain, modular firms producing many individual modules will pay greater proportions of their revenues towards intermediate firms along the supply chain. Thus we expect that the proportion of revenues spent on purchased intermediate inputs will be higher, and that it will be positively correlated with the firm's level of modularity.

The preceding leads us to specify a model of industry modularity as follows:

Let:

$$\epsilon = EnergyIntensity_i$$

$$\Theta = Technology_i$$

$$\iota = Inter - IndustryInteractions_i$$

$$\tau = TransportationCost_i$$

$$\pi = PurchasedIntermediateInputs_i$$

$$Modularity_i = \beta_0 + \beta_1\epsilon_i + +\beta_2\Theta_i + \beta_3\iota_i + \beta_4\tau_i + \beta_5\pi_i + \mu_i \tag{1}$$

The simplest functional form for the relationship in Equation '(1)' is linear and, absent any strong priors regarding other functional forms, we will operationalize (1) as a linear model. We hypothesize that β_1 is negative and that the other coefficients, not including the intercept, are positive.

IV. Regression Analysis

I. The Dependent Variable: Modularity

Our dependent variable is a binary variable for Modularity. As explained above, we identify a set of 79 industries commonly used as examples of modularity (Appendix A) and assign them an a priori modularity index value of 1. We identify a second set of 40 industries that are recognizably not modular (Appendix A) and assign them an a priori modularity index value of 0. As explained further below, we have data for a total of 305 industries. Our objective is to use the results of the regression analysis of the sample of 119 industries with a priori assignments to calculate predicted modularity potentials for the other 186 industries.

II. The Independent Variables

The right side of Equation (1) proposes variables to represent the hypothesized characteristics of modular industries introduced above. We will estimate the weights for the characteristics in our modularity index using multiple linear regression. Our observations are industries in the United States economy using the 2007 North American Industry Classification System (NAICS) codes, which divide the U.S. economy into industries by grouping firms with similar products and services together. Our data for all but one of the independent variables was calculated from the U.S. Bureau of Economic Analysis's 2007 Industry-by-Industry Direct Requirements table. Our measure of Purchased Intermediate Inputs came from Returns of Active Corporations data from the U.S. Internal Revenue Service published in 2010. The specific data used as our measure for each independent variable included in the regression analysis is described below.

II.1 Energy Intensity

We measure total energy input per dollar of output as the sum of the proportions of purchases from Oil and Gas Extraction (NAICS: 21100), Coal Mining (NAICS: 212100), Drilling Oil and Gas Wells (NAICS: 213411), Other Support Activities for Mining (NAICS: 21311A), Electric Power Generation, Transmission, and Distribution (NAICS: 221100), and Natural Gas Distribution (NAICS: 221200).

II.2 Technology

We measure each industry's level of technology by its use of electronic components as summarized in the proportion of its purchases from Semiconductors and Electronic Components (NAICS3344).

II.3 InterIndustry Interactions

We measure interindustry transactions as the number of industries with which each industry transacts, including only transactions greater than .5 percent of all purchases.

II.4 Transportation Costs

We measure relative transportation costs for each industry as the sum of the proportions purchased from Air Transportation (NAICS: 481000), Rail Transportation (NAICS: 482000), Water Transportation (NAICS: 483000), Truck Transportation (NAICS: 484000), Transit and Ground Passenger Transportation (485000), and Warehousing and Storage (493000).

II.5 Purchased Intermediate Inputs

We measure a firm's relative level of purchased intermediate inputs as the Cost of Goods Sold as a percentage of total returns. These data were gathered from the U.S. Internal Revenue Service, which does not use the NAICS code classifications. We manually matched IRS industries to the most similar NAICS industries. However 83 of the 388 industries had to be excluded from our analysis because of a lack of a suitable match in the IRS data. The number of remaining industries is 305.

Table 1: Estimation Results for the Modularity Equation

Variable	Coefficient	Standard Error	z-Statistic	p-Value
C	-19.32031	7.261855	-2.660520	0.0078
Energy Intensity	-12.58667	9.263385	-1.358755	0.1742
Interindustry Interactions	-0.025078	0.008683	-2.888219	0.0039
Transportation Cost	30.24451	27.46787	1.101087	0.2709
Purchased Intermediate Inputs	43.69590	14.95524	2.921778	0.0035
McFadden Pseudo R-squared	0.943224	-	-	-

III. Estimation of the Regression Model

With data for the sample of 119 industries with a priori assigned modularity index values of 1 or 0, we estimate the parameters of Equation 1. We first attempted to use ordinary least squares to estimate a linear probability model, but it yielded predictions of modularity greater than 1 and less than 0, an unacceptable outcome. Both probit and logit models constrain the predicted values to the unit interval. We estimated these nonlinear models using the method of maximum likelihood. However, with both models the data were such that we were unable to obtain estimates of the standard errors of the coefficients in any specification that included both Technology and Purchased Intermediate Inputs. Consequently is was necessary to eliminate one of the two variables causing the problem. Because models with Purchased Intermediate Inputs provided a better fit to the data than models with Technology, the former were retained. Next we compared the results for the logit and probit models, which were very similar, but because the probit model yielded stronger results, especially in terms of the significance of individual coefficients, we chose it. The estimated standard errors of the individual coefficients were corrected for possible heteroscedasticity using the Huber-White procedure so that they are heteroscedasticity consistent.

IV. Estimation Results

Estimation results are reported in Table 1. The overall explanatory power of the model is very high, with a McFadden Pseudo R-squared vale of .94. As expected, the sign of Energy intensity is negative and the signs of Transportation Cost and Purchased Intermediate Inputs are positive. The unanticipated negative sign for Interindustry Interactions may indicate that modular industries purchase modular components that already incorporate the products of a number of other industries so that fewer and not more interindustry interactions would be expected for modular industries. This interpretation is reinforced by the fact that the coefficient for Interindustry Interactions is highly significant with a p-value of .39 percent. The coefficient for Purchased Intermediate Inputs is also highly significant. While the coefficients for Energy Intensity and Transportation Cost are not very significant, we are not overly concerned because the purpose of the model is to make and apply predictions of modularity for the industries that are not known a priori to be modular. Additionally, the standard errors of a few of the independent variables are rather high, but this is not abnormal in a model with a binary dependent variable, as the variability is over a (1,0) plane.

The predictive performance of the equation is excellent as shown in Table 2. The equation

Table 2: Predicted Values Using the Estimated Equation

	Dep=0	Dep=1	Total
Expected (No. of Dep=0)	38.58	1.29	39.87
Expected (No. of Dep=1)	1.42	77.71	79.13
Total	40.00	79.00	119.00
Correct	38.58	77.71	116.29
Percent Correct	96.45	98.36	97.72
Percent Incorrect	3.55	1.64	2.28

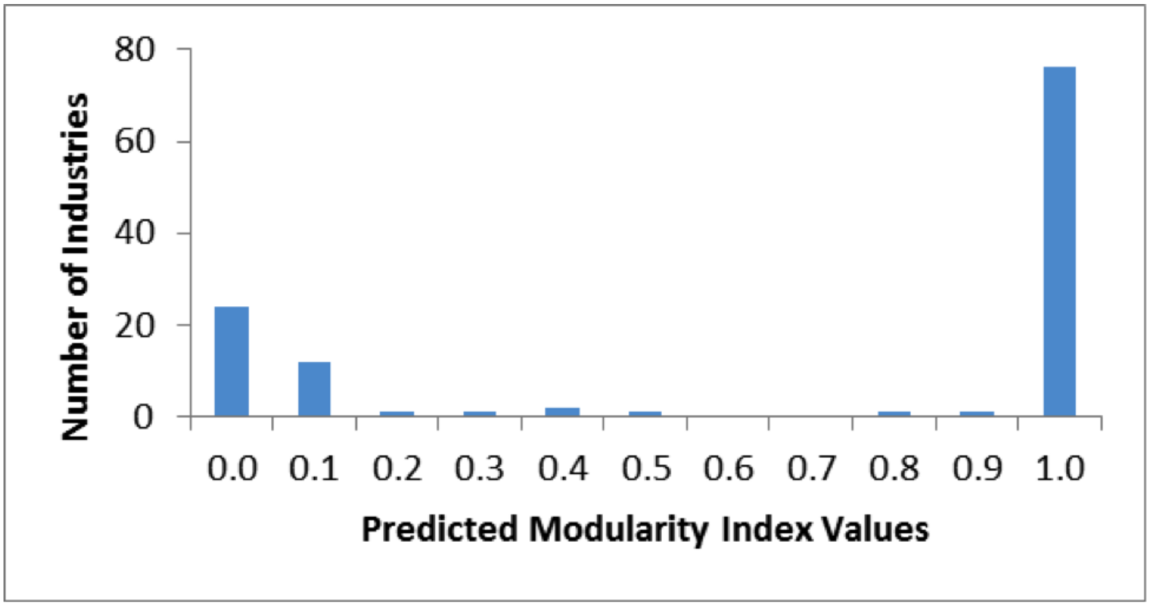

Figure 1: Predicted Modularity for the Sample of 119 Industries

successfully separates the industries with known a priori modularity as well: 96 percent of the a priori non-modular industries are correctly predicted and 98 percent of the a priori modular industries are. Modifying the number of industries used in the sample, we found that the results were robust with respect to sample size. We also examined the effects of misclassification of industries as modular and non-modular and found that the results were also robust to moving as many as 10 percent of the observations from one category to the other.

The disparity between the predicted 1's and predicted 0's presented in Figure 1 represents the ability of the predicted index values to divide the sample industries into modular and non-modular categories.

V. Calculating Predicted Modularity Index Values for Out-of-Sample Industries

Because we have the data for the 186 out-of-sample industries for the variables in the equation, we can use the equation to estimate modularity index values for the out-of-sample industries. Figure 2 shows that, among the out-of-sample industries, the index does well in separating them into what

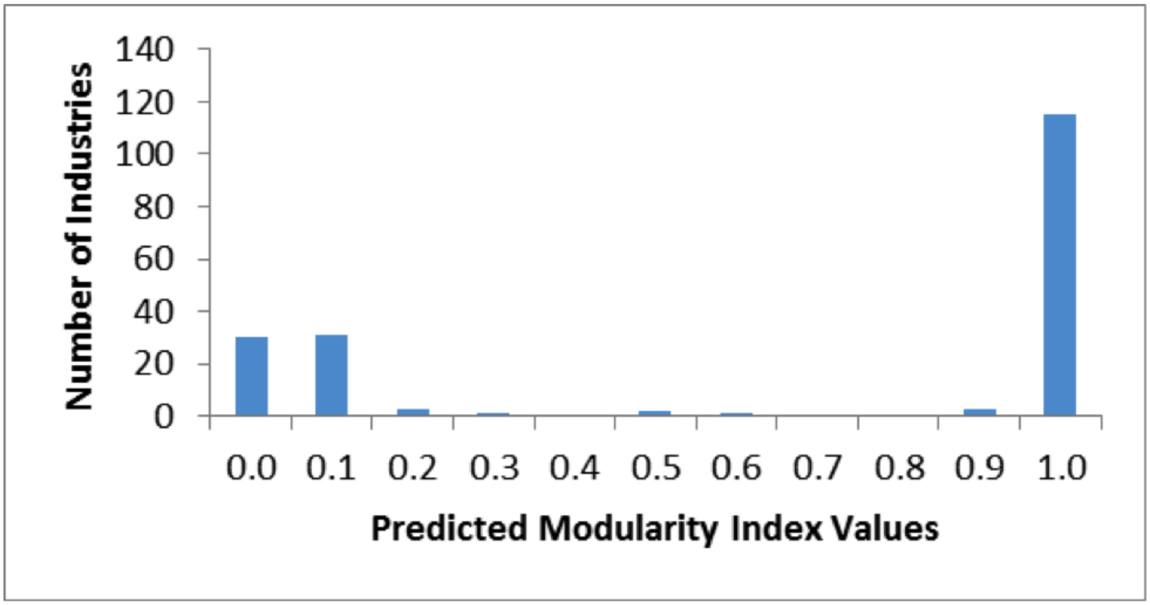

Figure 2: Predicted Modularity for 186 Out-of-Sample Industries

might be called "potentially modular" and "probably not modular" industry categories. Appendix A lists the predicted index values for all 305 industries. There are some anomalous results for which we do not have good explanations at this time. For example Household Cooking Appliance Manufacturing (Appendix A, Row 79) was classified as modular a priori but its predicted index value turned out to be only .123.) Additional investigation of such cases to see if there is a bases for re-classifying them a priori might lead to refined results.

V. Application of Results

Examining the predicted values in Appendix A starting on row 120 reveals that there are a number of manufacturing industries that we originally did not classify as modular but which have predicted index values of 1. We originally thought that many of these involved potentially continuous processes (e.g., Carpet and Rug Mills -Row 136) that would not lend themselves easily to modularization. The results of the analysis indicate that this assumption ought to be re-examined for a number of manufacturing industries. There are also some industries that would be classified as potentially modular based on index values of 1 but which seem entirely non-modular in character (e.g., Stone Mining and Quarrying – Row 181). So some judgment must be exercised in interpreting the results for "potentially modular" industries. The index classifies all kinds of services as non-modular (giving them index values of 0) which seems intuitively to be correct. But some industries that fall into the "probably non-modular" category might be potentially modular (e.g., Periodical Publishers – Row 266). So some judgment must be also exercised in interpreting the results for "probably non-modular" industries. In spite of some weaknesses of the sorts identified in the preceding two paragraphs the index appears to have promise as an aid to identifying industries that might be modularized and thereby experience lower levels of cost. Next steps would include more intensive examination of some of the "potentially Modular" industries and find those that, in fact, have not modularized and then see if modularizations are actually possible.

VI. Conclusions

The modularity index of this paper may be a useful tool to aid in identifying modular and non-modular industries and making recommendations regarding production process efficiency increases. Understanding the roles played by the independent variables in the model can shed light on the market positions of firms in modular industries. They often face variable market conditions with respect to the models variables, as they depend on many other firms to source, transform, transport, and assemble their final products. By better understanding their position within the market, modular firms can transform their production processes and their organization in order to drive prices down and increase production efficiency. Modularity has become central in discussions of efficiency increases and cost-reductions. Identifying and including new indicators of modularity in the model may increase its robustness and utility.

VII. References

VIII. Appendix