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A conceptual view of exergy destruction in mergers and acquisitions☆

Gökçen Arkalı Olcay[a,*], M. Atilla Öner[b], Ali Bahadır Olcay[c]

[a] School of Management and Administrative Sciences, İstanbul Şehir University, Turkey
[b] Management Application and Research Center, Yeditepe University, Turkey
[c] Department of Mechanical Engineering, Yeditepe University, Turkey

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ABSTRACT

Company mergers are complex where several firm-specific and contextual factors interact with each other impacting the outcome of the process. Although many firms merge with or acquire others to increase the value of their firms, have more market power and gain more ability to negotiate with suppliers or customers, most of mergers and acquisitions result in failures. Despite the poor performances, firms continue to merge and acquire. The existing literature on the other hand lacks in providing a robust theory to the issue of poor post-merger performance. This study thus responds to exploring the issue of high failure rates in mergers and acquisitions in an entirely different way. As the first output of a research programme on the conceptual, theoretical and empirical issues in merger and acquisitions research, we conceptualize the loss of performance or exergy in mergers and acquisitions using thermodynamic analysis of the mixing process in physical systems. Three propositions are developed that conceptualize the ideal conditions for mergers in terms of *firm size*, *relatedness between the merging firms* and *the ambient states*. The *exergy loss* due to merging increases with the increasing levels of *strategic or cultural incompatibility* between the two firms. When the sizes of two firms differ, it is preferable for the larger firm to have *higher knowledge base* than the smaller firm. Lastly, the *knowledge intensity of the country* that the merging takes place as well as the *relative knowledge base* of the merging firms do interact and change the post-merger performance significantly.

1. Introduction

The study of Haucap and Stiebale (2016) on pharma mergers is quite interesting in the sense that R&D and patenting activities of the merged entity decline substantially after merging. The new merged company is not the only one harmed in this situation, innovation activities of the non-merging rivals do also decrease. While this is one-industry case specific to pharmaceuticals, there are many other studies questioning the goodness of mergers and acquisitions in terms of various performance metrics such as *innovation* (Ahuja and Katila, 2001; Cefis and Marsili, 2015; Haucap and Stiebale, 2016; McCarthy and Leendert, 2016; Prabhu et al., 2005), *financial performance* (Agrawal, 2000; Andre et al., 2004; Datta et al., 1992; King et al., 2004), and *managerial perspectives* (Bauer and Matzler, 2014) across various industry and country context.

The phenomenon of merging and acquiring created an immense study area for scholars in management since 1970s (Cartwright and Schoenberg, 2006; Meglio and Risberg, 2010). There is still much debate on the antecedents, moderators and outcomes of mergers and acquisitions since a significant portion of such mergers and acquisitions fail within short durations of merging or acquiring. Several schools of thought within the field of management including finance, organizational behavior, strategy, and process management approached the issue using alternative windows of insights (Bauer and Matzler, 2014). However, the expectations to create synergy and increase the efficiency of work done in the merged system do not work well as intended (Andre et al., 2004; Cartwright and Schoenberg, 2006; Harrison et al., 1991; Prabhu et al., 2005). The field is also scarce in terms of existing theories in explaining the merging process in business (Christensen et al., 2011; King et al., 2004). While agency theory (Ahuja and Katila, 2001; Haleblian et al., 2009) and resource-based view (Ahuja and Katila, 2001; Bauer and Matzler, 2014; Cefis and Marsili, 2015; Chatterjee, 1986) are utilized to understand the variability in post-acquisition or post-merger performance, they are not sufficient.

Combining the power of two separate systems in one hand does not result in a superb system most of the time as the extensive amount of academic studies from many different disciplinary perspectives published on mergers and acquisitions indicate. Besides, scholars have not

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* Corresponding author.
E-mail addresses: gokcenarkali@sehir.edu.tr (G.A. Olcay), maoner@yeditepe.edu.tr (M.A. Öner), bahadir.olcay@yeditepe.edu.tr (A.B. Olcay).

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succeeded in explaining the reasons for failures (or successes) in mergers and acquisitions that lead to an integrative theory of what have been accumulated in the forms of empirical findings in the extant literature (Haleblian et al., 2009). Nevertheless, firms continue to merge and acquire despite the large-scaled evidence that most of these efforts are likely to underperform expectations. Thus, academics from different areas including business schools, applied economics and other related areas will continue to study whether it is worth to merge and acquire or not.

In light of all these, we offer a different perspective in understanding the interaction of two separate companies under one roof in an effort to become more competitive, grow more, or enlarge the nature of the business. Could the universal theories of thermodynamics have a stake in explaining the unseen mechanisms that take place in mergers and acquisitions? If so, how could this phenomenon be conceptually approached?

Thermodynamically, when two systems at different states (pressure, composition or temperature) are mixed, some of the potential useful energy (so called exergy) is destroyed and some entropy is generated. In terms of the engineering terminology, exergy is a measure of useful work whereas entropy is a measure of molecular disorder. If the two systems are at identical states, then the total exergy of the combined system becomes the sum of the exergies of the entities before the mixing. Theoretically, the total exergy of the combined system is always less than the sum of the exergies of the entities before mixing when the two are not at identical states (Çengel et al., 2002). While the energy content of the combined system does not change, the capability of the combined system to produce useful work decreases according to the first and second laws of thermodynamics.

On the other hand in business context, most mergers and acquisitions result in an overall loss of performance as were emphasized in a vast number of studies in the prior literature (Andre et al., 2004; Cartwright and Schoenberg, 2006; King et al., 2004) despite the obvious intentions of both sides towards increasing the firm value following the merger or acquisition. Merging is a complex process that makes the decision making more difficult for responsible managers on both sides requiring looking at the problem from alternative perspectives. Thus, we propose a model to explore the organizational phenomenon of mergers and acquisitions via analyzing physical mixing systems.

While merging has its own dynamics starting from the very initial stage of mutual interests and intentions of the merging companies including negotiations, handshaking and integration process all the way to forming one new company (Oner and Zan, 2007), modeling business mergers with thermodynamics could provide an entirely different way to look at the issue of merger failures. We lean on a deductive approach in building a conceptual model exploring both why and how merging could result in loss in exergy or wealth by drawing an analogy to physical mixing process explained by the fundamental laws of thermodynamics. In building such an abstract model, we are well aware of the limitations of system modeling as Louie (2010) articulate on the basis of the earlier studies of Robert Rosen on anticipation systems, "*A natural system is almost always more than any model of it. In other words, a model is, by definition, incomplete.*"

The underlying model of this study mapping from the realm of thermodynamics to the realm of organizations where physical variables such as *temperature*, *mass*, and *ambient conditions* are linked to variables such as *size*, *knowledge-base* and *culture in organizations* has thus its own limitations. While in its current form, the state variables are causally related to the outcome of the system as measured in exergy or wealth of the company, further assessments could take the study to an anticipatory level by incorporating the consequences of present actions in future back into the model as further elaborated in Louie (2010) and Rosen (1991).

However, as a starting point, we build a conceptual model to provide a theoretical explanation on why most mergers and acquisitions turn out less successful than planned rather than a description of a certain case (or collection of them) simulated by some empirical data. Completing the other pieces of links between mergers and mixing, developing research hypotheses and testing these hypotheses with real data form the subsequent stages of the research program that this study is derived from.

In blending the field of engineering (and physics) with the view of management studies, we offer avenues for possible future research to scholars in the field of business and management who study what happens to post mergers and acquisitions. Besides, we also aim to contribute to the thinking process of some who use well established analysis methods from engineering, physical science and biological science to look at larger scale socio-technical systems, and apply that analysis in interesting and imaginative ways to derive insights as compared to conventional approaches in such fields.

Based on the thermodynamic analyses of the conceptual model of this study, we posit three propositions. While merging always result in a loss of overall exergy, the degree of strategic or cultural fit between the firms affect the overall loss (performance) differently according to the propositions. Moreover, we analyze various other scenarios exploring the effects of relative sizes, the prior ambient conditions that merging firms originate from and the ambient of the country that merging takes place on post-performance as further discussed in Sections 3 and 4.

This paper is organized as follows. The dynamics of mergers and acquisitions where the post-merger or post-acquisition performance indicators and measures are explored is given in Section 2. Section 3 discusses the characteristics of thermodynamic systems linking thermodynamics to organization science. Lastly, how thermodynamics could benefit in understanding the unseen mechanisms of mergers and acquisitions are given in Section 4 with recommendations for companies as well as avenues for future research.

2. Dynamics of mergers and acquisitions

Companies merge with or acquire other firms for various motivations.[1] Standard motivations for horizontal mergers are to save money by eliminating duplicated functions (Spector, 2003), increase market power with a larger size having the ability to negotiate favorable long-term contracts with suppliers and customers (Kim and Singal, 1993) or reduce competition (Levin, 1990). On the other hand vertical mergers aim to get control over adjacent steps of production path to enhance synergy (Fan and Goyal, 2006; Lubatkin, 1983). However, apart from the type of mergers, firms do not benefit from merging based on the initial expectations of achieving greater performance in exponential orders or the existing antecedent variables in the literature lack of explaining the real benefits of merging and acquisitions.

There is not much value created by merging or acquiring as the evidence reveals in the literature which is reinforced by various perspectives of different schools of thought (Andre et al., 2004; Cartwright and Schoenberg, 2006; Haucap and Stiebale, 2016). In an attempt to understand the dynamics of successful mergers and acquisitions, we first elaborate on the multidisciplinary nature of mergers and acquisitions. Then, we identify commonly used metrics of post-performance and the factors that have the utmost importance in characterizing the success of mergers and acquisitions from the literature.

[1] We thank one of the anonymous referees for bringing to our attention the importance of motivations which is also closely related to the typology of mergers and acquisitions in exploring the post performance. While the type of merger as being horizontal, vertical or conglomerate (as common classifications of mergers and acquisitions) might certainly affect the post performance in different ways, we explore the dynamics of mergers and acquisitions of companies at similar states of size, technological knowledge and ambient conditions in developing the underlying conceptual model of this manuscript.

2.1. Multidisciplinary nature of mergers and acquisitions

Mergers and acquisitions is a multi-faceted phenomenon that requires exploring the subject from various viewpoints. Attention is drawn to the high failure rates of mergers and acquisitions in their editorial paper for the special issue of British Journal of Management on mergers and acquisitions by Cartwright and Schoenberg (2006). While the high failure rates make this phenomenon an exciting research field for various scholars across multiple fields, the concept in its nature is multidisciplinary and complex (Cartwright and Schoenberg, 2006) which in turn requires exploring the subject elaborately through different lens of schools of thought.

Four streams of research have been designated by Bauer and Matzler (2014) that tackle mergers and acquisitions success from the viewpoints of financial economics, strategic management, organizational behavior and process schools of thought. Most of these studies are fragmented, isolated and are constrained with their specific viewpoints of the problems. The very high failure rates of mergers and acquisitions, as documented between 70 and 90% with > 2 trillion dollars of acquisition costs call for a "robust theory" to understand the causes of such failures (Christensen et al., 2011).

Besides the prevalence of empirical research done in mergers and acquisitions, many review papers or meta-analyses on mergers and acquisitions are also found within the management literature cumulating the research up until their time to draw conclusions on the patterns of post-acquisition or post-merger performances and the antecedents and moderators of high performed mergers and acquisitions. We first explore the literature on post-merger or post-acquisition performance to further understand how successes and failures are distributed and which metrics are used in assessing the performance of mergers and acquisitions. Then, we elaborate on the factors, determinants and moderators that are prominent in explaining the performance of mergers and acquisitions in the literature.

2.2. Post-merger or post-acquisition performance

There are different streams of research on the performance effects of mergers and acquisitions assessed through various metrics such as financial performance, innovation performance or internationalization measures. While stock-market and accounting-based success measures are frequently employed on short-term periods just following the announcements of mergers and acquisitions, the importance of measuring the performance from managerial perspectives has been stressed by Bauer and Matzler (2014). In building the empirical model for measuring the success of SMEs, they thus use multiple measures of performance based on both subjective and objective assessments of managers.

Findings of an earlier meta-analysis of 41 prior empirical studies that are published between 1977 and 1989 indicate that while market performance of bidding firms do not improve, target firms might benefit from regulatory changes and tender offers (Datta et al., 1992). Reviewing the literature on the financial post performance of mergers and acquisitions, Agrawal (2000) conclude that long-run stock returns are negative following mergers. Similarly, Andre et al. (2004) find that acquirers significantly underperform in the long-run based on > 250 Canadian mergers and acquisitions between the years 1980 and 2000.

In another meta-analysis study of post-acquisition performance of acquiring firms based on 93 prior studies, King et al. (2004) conclude that acquisition activity does not positively improve acquiring firms' performance, there is even a modest level of negative effect in post-acquisition performance of such firms. Their study uses multiple measures of performance including stock and accounting measures and assesses the existing empirical research based on the most commonly studied variables including conglomerate firms, related acquisitions, method of payment and acquisition experience. Using mergers and acquisitions data from 2001 to 2012 in ASEAN countries, Rao-Nicholson et al. (2015) calculate the average post-performance deterioration to be as 0.55% and 2.25% for raw performance and industry-adjusted performance measures of ROA, respectively. Overall, neither acquiring firms benefit financially from acquisitions nor these factors are found to be associated with post-acquisition performance which in turn implies unspecified factors might explain the variance in performance differences.

Though less, there also exist other empirical studies on the positive effects of mergers and acquisitions on post-acquisition or post-merger financial performance. An earlier study based on 50 largest mergers between U.S. public industrial firms between 1979 and 1983 draw attention to increases in operating cash flow returns because of the increases in asset productivity with respect to their peers in the same industry following the mergers (Healy et al., 1992). Despite the positive average return on cash flows, the authors conclude that there is decrease in cash flow returns in one quarter of the sample that further quests the overall success of mergers and acquisitions. Thus, their study is concluded with a recommendation to explore a smaller sample in more detailed analysis to pinpoint the forces of success in mergers and acquisitions. There exist some other studies showing positive abnormal returns following the tender offers in the short-run while the long-run performance is negative based on a review of the literature on mergers and acquisitions by (Agrawal, 2000).

With regards to innovation performance of post mergers and acquisitions, several measures including number of patent applications, quantity and novelty of inventions, count of new products, innovation level, patents and R&D spending are explored in the prior literature (Ahuja and Katila, 2001; Cefis and Marsili, 2015; Haucap and Stiebale, 2016; Makri et al., 2010; McCarthy and Leendert, 2016; Prabhu et al., 2005). Only technological acquisitions result in higher performance of innovation measures according to (Ahuja and Katila, 2001). Size could be a primary determinant in post-performance such that larger firms benefit most from mergers and acquisitions (Cefis and Marsili, 2015). On the other hand, type of firm's knowledge could explain the variability of post-performance as it is shown in Prabhu et al. (2005) such that firms with greater deep internal knowledge could achieve higher post-acquisition performance in innovation.

Success of mergers and acquisitions are also measured on metrics other than financial and innovation measures. Success is measured from a managerial perspective based on the ratings of managers involved in either parties of mergers and acquisitions (Bauer and Matzler, 2014) or integration metrics in the form of post-acquisition integration (Lee et al., 2015), human and task integration to innovation (Bauer et al., 2016), and post-merger integration and synergy (Weber et al., 1996).

The literature is extensive in measuring the success from various perspectives with data across countries and industrial sectors including longitudinal data over longer periods. Different methodologies employed in such studies also make cross comparisons among such studies difficult in reviewing the literature in the field of mergers and acquisitions (Meglio and Risberg, 2010). All given, majority of such studies report poor post-performance associated with mergers and acquisitions (Cartwright and Schoenberg, 2006; Haucap and Stiebale, 2016; King et al., 2004). Next we explore the factors that are associated with the success of mergers and acquisitions.

2.3. Performance factors for the success of mergers and acquisitions

Various determinants of mergers and acquisitions' success were identified in the prior literature depending on from which perspective such as financial economics, strategic management, organizational behavior or process view the problem is handled. Several studies point to *cultural fit*, *strategic fit*, *firm and industry characteristics*, and other aspects of the merging or acquisition process as the main determinants of the success of mergers and acquisitions (Bauer and Matzler, 2014; Cartwright and Schoenberg, 2006; Weber, 1996). Issues are frequently classified according to the success of mergers and acquisitions in two main lines as premerger phase and post-merger phase issues. In that

Table 1
Pre-merger (acquisition) performance factors.

Factors	Metrics	Performance measures used	Sources
1. Cultural fit			
Cultural differences at the organizational level	Top management team compatibility - Chatterjee et al.'s (1992) & Datta's (1991) metrics	ROA, effectiveness of the integration, shareholder value, synergy realization, effective integration, cross border acquisition performance	Ahammad et al. (2016), Stahl and Voigt (2008), Weber (1996), Weber et al. (1996)
Cultural differences at the national level	Hofstede's (1980) dimensions of national culture, Kogut and Singh (1988) index, Self-developed scales	Integration-innovation performance, shareholder value, synergy realization, effective integration, cross-border acquisition performance	Ahammad et al. (2016), Bauer et al. (2016), Morosini et al. (1998), Stahl and Voigt (2008), Van der Vennet (1996), Van Oudenhoven and Van Der Zee (2002)
Cultural distance	Composite index of four dimensions by Hofstede (1980)	Shareholder value creation	Datta and Puia (1995)
Cultural compatibility	Compatibility scale of Jöns et al. (2007) and Jöns et al. (2005)	Performance measured from a managerial perspective	Bauer and Matzler (2014)
Autonomy removal	23 items questionnaire by (Weber, 1996), Instrument derived by Vancil (1979), Goehle (1980) and Cray (1984)	ROA, effectiveness of the integration	Weber (1996), Weber et al. (1996)
Top management Commitment	Modified version of Porter's (Porter et al., 1974) commitment scale	ROA, effectiveness of the integration	Weber (1996)
2. Strategic fit			
Relatedness	Horizontal or vertical acquisition operationalized by Harris and Ravenscraft (1991)	Shareholder value creation	Datta and Puia (1995)
Similarity on knowledge base	Proportion or number of patent subclasses shared by acquirer and target, Relative size of acquired knowledge base	Innovation output, patent counts	Ahuja and Katila (2001), Prabhu et al. (2005)
Technological complementarity	Number of patents in the same subcategory but in different patent subclasses	Invention quantity, quality and novelty	Makri et al. (2010)
3. Firm and industry characteristics			
Firm size	Number of employees	Innovative behavior	Cefis and Marsili (2015)
Geography	Haversine formula based distance between GPS addresses	Patent count	McCarthy and Leendert (2016)
Knowledge transfer	Schoenberg (2004) index	Cross border acquisition performance	Ahammad et al. (2016)
Employee retention	Ranft and Lord (2000) index	Cross border acquisition performance	Ahammad et al. (2016)

classification, strategic fit and cultural fit form premerger phase factors whereas issues related to integration and the characteristics of the merging process are to be considered under post-merger phase.

Integrating two different organizations along a line to form one is a critical issue that needs to be done in care. Factors that are effective during the integration phase also comprise an important component of post-performance. As an example, human and task integrations act differently on performance as Bauer et al. (2016) suggest that the former has a negative whereas task integration has a positive effect on post-performance measured in innovation outputs. However, in modeling mergers and acquisitions as equivalent to thermodynamic systems of mixing two matters at different states and environmental conditions, pre-merger or pre-acquisition conditions or factors become more relevant than the integration process characteristics. Therefore, we extract an incomplete[2] set of metrics used to measure pre-merger (pre-acquisition) phase factors that are highly associated with the success of mergers and acquisitions in the prior literature as shown in Table 1.

2.3.1. Cultural fit

Based on a meta-analysis of 46 prior studies on mergers and acquisitions, Stahl and Voigt (2008) suggest two contrasting roles of cultural differences on the performance of mergers and acquisitions that are forming significant barriers on merging entities and creating value through learning and complementing each other. Finding support for both roles, Stahl and Voigt (2008) differentiate between the opposing effects of cultural differences depending on various measures of performance (i.e., synergy realization, shareholder value and socio-cultural integration), employed moderators, research design and sample characteristics of these studies.

In exploring the role of cultural fit, autonomy removal and top management commitment on the merged entities' financial performance as measured by ROA, Weber (1996) finds negative association between the financial performance and cultural differences for firms that are in banking sector. However, financial performance is positively associated to autonomy removal and top management commitment in nonbanking and full samples including all firms. Similarly, Bauer and Matzler (2014) show the positive effect of cultural fit on success of mergers and acquisitions based on an empirical test of 106 SME transactions that took place between 2005 and 2008 in Germany.

Although the tendency is towards the negative impact of cultural differences (i.e., the lack of cultural fit) on post-acquisition or post-merger performance (Ahammad et al., 2016; Weber, 1996), the effects of similarity on post-performance are a two sided concept with evidence on positive effects, too. The difference in cultural norms between two countries could improve cross-border acquisition performance as shown in a sample of 52 cross-border acquisitions that took place in Italy between 1987 and 1992 (Morosini et al., 1998). Besides, there exists studies showing the insignificant effect (no effect) of national cultural differences on post-innovation based on the argument that homogeneity in cultures between the two countries will ease the integration process of the acquired firm (Bauer et al., 2016).

Cultural differences can also contribute to explain the post-performance in other ways. According to Ahammad et al. (2016) cultural differences at organizational level mediate the relationship between knowledge transfer and cross-border acquisition success where the knowledge transfer is measured by the degree of the knowledge transmitted to the acquired firm in 11 areas including R&D, operations, strategic planning and marketing. However, cultural differences at national level are found to have no effect on cross-border acquisition performance in the same model.

[2] The current manuscript is based on 36 papers from our initial list of 215 papers from 18 different journals between 1980 and 2017.

2.3.2. Strategic fit

Several studies in the literature refer to the role of similarity in terms of horizontal and concentric mergers in the success of synergy achieved following such mergers (Chatterjee, 1986; Weber et al., 1996). In some of these empirical studies, the impact of similarity (e.g., with respect to knowledge base) on innovation performance is found to be nonlinear (Ahuja and Katila, 2001; Prabhu et al., 2005). An inverted u-shape relationship between similarity and innovation output following the acquisition is shown in another study where similarity is measured by the proportion of patent subclasses shared by the acquirer and the target firm (Prabhu et al., 2005). This study concludes that a moderate similarity in knowledge between the acquirer and target firm results in more innovations following the acquisition. Thus, both high and low knowledge similarities do not help mergers in terms of boosting their innovation performances. Findings of Ahuja and Katila's (2001) study based on a longitudinal data of 72 leading chemical firms' acquisitions are also on the same line supporting this view on the nonlinear effects of similarity in terms of relatedness of the acquired knowledge base. This study also evaluates absolute and relative sizes of the acquired knowledge base on innovation output where the absolute size has a positive whereas the relative size has a negative impact on post-acquisition innovation output.

Whether complementarity works better than relatedness or fit (strategic or cultural) is another area for debate on the success of merged or acquired units in the wide range literature of mergers and acquisitions. Complementary scientific and technological knowledge of the merging entities drive novelty resulting in more and higher quality innovations based on a sample of 95 high-technology mergers and acquisitions according to Makri et al. (2010).

2.3.3. Firm and industry characteristics

Firm size is also found to affect the innovative behavior of the combined entity in mergers and acquisitions. While both small and larger firms benefit from mergers and acquisitions, larger firms have higher chances of being more actively involved in innovation following the acquisitions or mergers as compared to small firms for whom the benefits are usually limited to just crossing the innovation threshold (Cefis and Marsili, 2015).

Geography is another factor that could have an impact on post-performance of acquisitions or mergers (McCarthy and Leendert, 2016; Prabhu et al., 2005). The physical distance between the acquired or merged firms matter in the sense that every 1000 km results in a loss of 19 patent applications in technological acquisitions as the distance increases transaction, monitoring and information costs (McCarthy and Leendert, 2016). There also exits other factors that are investigated in the literature as how they affect the post-performance. Both the degree of the knowledge transferred to and retained employees of the acquired firm have a positive effect on post-acquisition performance (Ahammad et al., 2016). On the importance of employee retention and turnover, (Butler et al., 2012) refer to the role of top management turnover in explaining the significant variance in post-performance. The expertise, leadership and oversight of the top management team of the acquired firm play a critical role on post-acquisition performance finding support from the resource-based view of acquisitions.

Strategic and cultural fit between two firms are empirically shown to have significant effects on post-performance besides effects of certain firm and industry specific factors such as firm size, geography and industry characteristics. Could firm specific variables that play a role in the post-performance of two merging companies represent states of a physical mixing process of two systems? We turn to the literature to explore how and where thermodynamics find a place across the vast areas of sciences (social and natural) in an effort to link mixing to mergers and acquisitions.

3. Characteristics of thermodynamic systems

We first elaborate on the use of thermodynamics in other sciences including biology, ecology, literature and arts in the first part of this section. In the second part, we link thermodynamics to organization science by developing three propositions based on hypothetical physical system calculations.

3.1. Thermodynamics in other sciences

The principles of thermodynamics had found many applications in fields other than natural sciences including cybernetics, literature and economics. The first law is on the conservation of energy and states that energy can only change forms during a process in other words it can neither be created nor destroyed. Although the conservation of energy is guaranteed with the first law, only the useful part of energy (i.e., exergy) could be transferred to real work resulting in an increase in the total unavailable part of the energy (i.e., entropy) of the system and its surroundings. Drawing attention to the rapidly depleting natural resources of energy, Ayres (2016) argues that life on Earth might not be able to continue unless the economic theory is aligned with the laws of thermodynamics. Using exergy analysis in mixing processes, Çengel et al. (2002) show that bigger does not necessarily mean better offering future avenues on the use of thermodynamics in other fields.

Gaining depth in only one field was acknowledged for a long time as the right way to solve life problems encountered in physical and social sciences; however, cross of knowledge and techniques across different fields could significantly contribute to the solutions of open problems through a completely different eye in these fields (Rapoport, 1950). In continuation with this argument, Rapoport (1950) discussed how the thermodynamics concept of entropy could be relevant in defining information in terms of negative order within the field of cybernetics. The concept of feeding on negative order was introduced earlier in the pioneer work of "What is Life?" by Schrodinger (1944) such that living organisms avoid the thermodynamic equilibrium (or maximum entropy) by disposing the entropy generated to the surroundings in the form of heat.

According to the thermodynamic functioning, living beings eliminate the material of high entropy that are taken into the system in the form of food which has high order but low entropy which in turn results in a decrease in the entropy of the inner system in order to remain alive (Schouten, 1953; Schrodinger, 1944). In line with this, Schouten (1953) proposed a formulation for the concept of endechy as the sum of order and disorder stating that the disordered component of a system grows at the cost of the ordered component for a given internal energy. Thus, it is possible for a system to do the opposite in other words to accumulate negative entropy from the environment and increase the self-order of the system which is accompanied by an increase in the surroundings of the system. Depending on the balance between negentropy gains and losses the dynamic sate of the system is determined such that the system loses order resulting in a senescence or deterioration state when a system generates more entropy than the information gained (Patten, 1959).

Therefore, in order to stay alive living systems absorb negative entropy from the surroundings and increase their order as studied by several scholars in the field of biology and ecology in the literature (Bednarz Jr., 1984; Gallucci, 1973; Goudge, 1953; Patten, 1959). The use of second law of thermodynamics in understanding the functioning of living organisms is questioned initially by such scholars (Gallucci, 1973; Jones, 1973); however, because livings systems have open boundaries without hitting to the dead state of maximum entropy they are able to attain a dynamic equilibrium as referred to by Kast and Rosenzweig (1972).

The concepts of thermodynamic systems have also long been contemplated in fields other than biology and ecology. Thermodynamics has been used to explain the act of composing arguing that the orderliness of the written composition created is compensated by an increase in the entropy of physical system of the writer (Freund, 1980). Art, in the form of a painting or in the human motion of a dance also shows a tendency to minimize entropy in order to unitize or order the things that make art (Gray, 1981).

3.2. Linking thermodynamics and organization science

Our starting assumption is that merging two companies at states representing their *size*, *knowledge base*, *company culture* or some other *firm-specific characteristics* can be modeled similar to mixing two systems in thermodynamics. While this assumption deserves further study, testing and explanation (see Footnote *), exergy could be an appropriate proxy for wealth (representing some economic variable) in the corresponding business model.

Changing the states of such a hypothetical model results in varying outputs of the dynamic system which could be measured in exergy. When it comes to how exergy is related to energy, one may turn to the laws of thermodynamics and the very neat expression of *Reiner Kümmel* in his own words as follows. Energy is conserved in all processes based on the first law of thermodynamics; however, "*Energy consists of valuable exergy, which can be converted into useful work, and useless energy, which is, for instance, heat dumped into the environment*" (Kümmel, 2013). Thus, energy conversion or exergy destruction enables the growth of wealth in industrial economics. There also exists other views on relating exergy to wealth or some other economic variable such as Ji and Chen (2006) associate exergy to the *real wealth* and Ayres et al. (2003) reformulate the idea of growth engine using energy inputs, i.e., useful work or exergy. Thus, exergy as one system's quality or potential to do work could be assumed to correspond to an economic variable representing the performance of the system in company mergers.

In an effort to link the physical systems of mixing to merging in organizations, we start with an analysis of a physical mixing system. Two closed systems initially apart from each other are chosen to study mixing of systems and provide physical mechanism among them. Fig. 1 shows System 1 and System 2 before and after mixing process. In thermodynamics, a partition is typically placed between two systems to maintain these systems separated prior to mixing states; then, the partition between systems is removed to allow mixing of two systems to reach their joint final equilibrium state. P_1 and T_1 indicate pressure and temperature of System 1 before mixing while P_2 and T_2 represent System 2's pressure and temperature values prior to mixing. Once the partition is removed, two systems expand to fill the entire space and they eventually attain an equilibrium point with new pressure and temperature values. In here, new pressure and temperature values are referred as mixture's pressure (P_{mix}) and temperature (T_{mix}).

Three different scenarios are analyzed based on the mixing of two systems given in Fig. 1. Mixing same substances with same mass which corresponds to merging companies of similar sizes in the same industrial sectors are studied in the first scenario. In the second scenario, the mass of the substance in the second system is varied while the mass of the substance in the first system is kept constant. This type of mixing is associated with merging companies of different sizes in the same industrial sectors. As for the third scenario, mixing same substances at different ambient states are analyzed. Here, different ambient states are considered as different countries that companies of the same industrial sectors to be merged reside in.

3.2.1. Scenario 1: mixing same substances with same mass or merging firms of similar sizes in the same industrial sectors

Both systems in Fig. 1 is considered to contain 1 kg of air at 100 kPa.

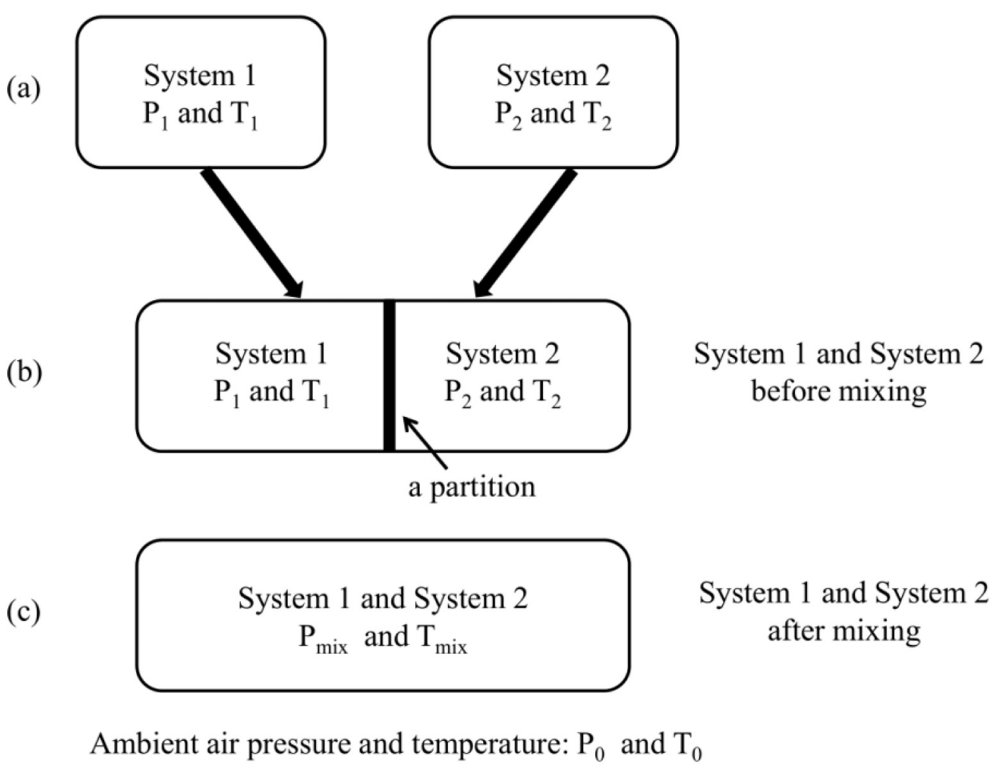

Fig. 1. Schematic of two closed systems before and after mixing; (a) two physical systems at different values of temperature and pressure (b) System 1[1] and 2 are brought together and a partition is placed to separate System 1 from System 2 (c) the partition is removed and systems are allowed to expand by filling the entire space. [1]System 1 is "the acquiring firm", System 2 is "the acquired firm" in a merger and acquisition.

Table 2
Computations of the exergies of Systems 1 and 2 before and after mixing process and the exergy destruction for the mixture.

Temperature 1 (K)	Temperature 2 (K)	Mixture temperature (K)	Exergy 1*	Exergy 2**	Exergy total (before)	Exergy mixture (after)	Exergy destruction (%)
400	400	400	14.56	14.56	29.13	29.13	0.00
400	500	450	14.56	48.59	63.15	59.41	5.92
400	600	500	14.56	94.92	109.48	97.18	11.24
400	700	550	14.56	149.74	164.30	141.01	14.18
400	800	600	14.56	210.78	225.34	189.84	15.76
400	900	650	14.56	276.57	291.13	242.88	16.58
400	1000	700	14.56	346.10	360.67	299.49	16.96

*, ** Both systems have air with the same mass (i.e., 1 kg).

Air temperature in System 1 is kept constant at 400 K while System 2's temperature is allowed to vary from 400 K to 1000 K with a 100 K increment. The temperatures of air in Systems 1 and 2 are shown in the first two columns of Table 2. The temperature of the mixture for each temperature of System 2 is obtained using the first law of thermodynamics and given in the third column of Table 2. Air was assumed to behave as an ideal gas and specific heat values of air were obtained at ambient temperature of 300 K for all calculations in Table 2.

Exergy is generally defined as the maximum theoretical work that can be obtained from a system when the system undergoes a process from its current state to its ambient conditions. The exergy of a closed system (φ) can be calculated using Eq. (1) (Cengel and Boles, 2014). u_0, P_0, ν_0, T_0, s_0 represent internal energy, pressure, specific volume, temperature and entropy of the ambient air while u and ν refer to internal energy and specific volume of air in the system. Therefore, exergy values of System 1 and 2 are computed based on Eq. (1) and tabulated in the fourth and fifth columns of Table 2. The sixth column represents the sum of the exergies in Systems 1 and 2 before mixing.

$$\varphi = u - u_0 + P_0(\nu - \nu_0) - T_0(s - s_0) \tag{1}$$

When two gases are permitted to mix with each other, exergy destruction occurs during mixing process because of irreversibility. Therefore, mixture's exergy is calculated based on mixture's temperature and pressure using Eq. (1). It is noted that the irreversibility due to mixing causes mixture exergy to be less than the sum of exergies of systems 1 and 2. The difference in exergies is called as exergy destruction and provided in the last column of Table 2 for changing temperature values of the air (between 400 K and 1000 K) in System 2. The magnitude of exergy destruction is an indication of the degree of the irreversibility associated with mixing process. Larger exergy destruction always implies less efficient process.

The variation of exergy destruction of the mixture with the temperature values of System 2 is plotted in Fig. 2 to illustrate the effect of the difference of the two systems' temperature on exergy destruction. Although exergy destruction for the mixing process exhibits almost a linear increase at temperature values of System 2 between 400 K and 600 K, the increase in exergy destruction decreases drastically above 600 K implying high temperatures of System 2 yields nearly constant exergy destruction at approximately 17%.

When two systems of same mass are mixed in given ambient conditions, the total exergy of the mixture is always less than the sum of the individual exergies of both systems before mixing as illustrated in Table 2 and Fig. 2. Besides, the greater the temperature differs between

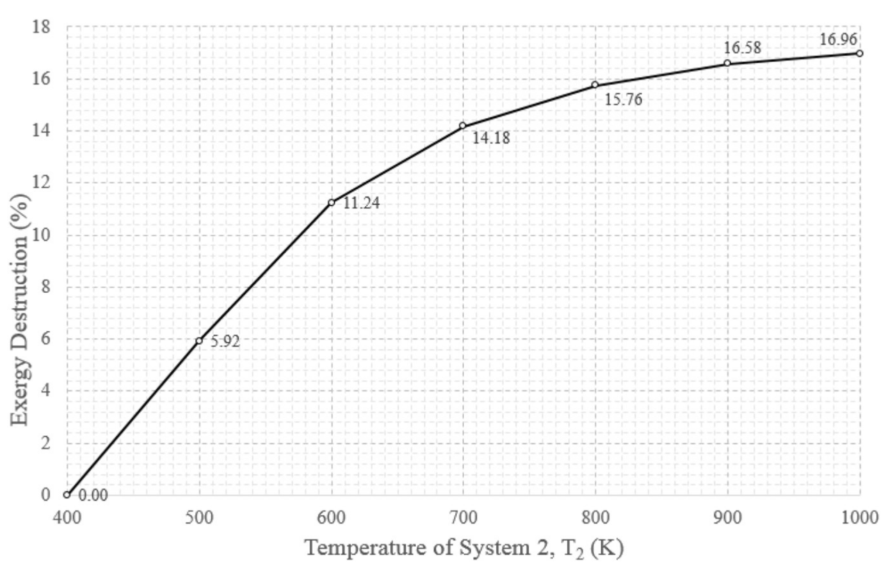

Fig. 2. Effect of air temperature in System 2 on exergy destruction of the mixture.

Table 3
Exergy destruction (%) with respect to the changing mass ratios (m_1/m_2) of 0.1 to 10 when two systems of air are mixed at different temperature values of the second system.

m_2	m_1/m_2 [a]	Exergy destruction (%) when						
		$T_2 = 400$	$T_2 = 500$	$T_2 = 600$	$T_2 = 700$	$T_2 = 800$	$T_2 = 900$	$T_2 = 1000$
0.1	10	0.00	3.73	10.46	16.93	22.32	26.63	30.03
0.2	5	0.00	5.40	13.44	19.92	24.63	28.00	30.41
0.5	2	0.00	6.58	13.85	18.51	21.35	23.07	24.11
1	1	0.00	5.92	11.24	14.18	15.76	16.58	16.96
2	0.5	0.00	4.36	7.68	9.32	10.10	10.44	10.53
5	0.2	0.00	2.30	3.85	4.54	4.82	4.92	4.91
10	0.1	0.00	1.28	2.09	2.44	2.57	2.61	2.59

[a] System 1: $m_1 = 1$ kg, $T_1 = 400$ K, $P_1 = 100$ kPa; System 2: m_2 varies between 0.1 kg and 10 kg, T_2 varies between 400 K and 1000 K, $P_2 = 100$ kPa; Environment: $T_0 = 300$ K, $P_0 = 100$ kPa.

two systems, the more exergy or useful work is destructed. The prior literature on merging and acquisitions reveal how cultural compatibility or strategic fit in the forms of relatedness, similarity in knowledge base or technological compatibility between the merging firms result in higher post-performance as shown in Table 1. Mixing same substances with same mass in similar ambient conditions can be considered a similar process to merging two companies of similar sizes in the same industrial sectors under given ambient conditions.

Based on the above discussion, it is possible to make an analogy between the difference in temperatures between two physical systems of mixing and *the cultural or strategic compatibility of two merging firms*. Now, we formulate the following propositions on the relatedness of the merging companies and the yielding post-performance.

Proposition 1a. When two firms of same size in the same industrial sectors at similar prior ambient conditions are merged, the overall performance of the newly formed organization will always be lower than the sum of the individual performances of firms before merging.

Proposition 1b. In merging two firms of same size in the same industrial sectors at similar prior ambient conditions, the degree of strategic or cultural compatibility between the merging firms affect the overall performance of the newly formed organization such that the more the firms are strategically or culturally incompatible, the lower the overall performance of the merging organization is.

3.2.2. Scenario 2: mixing same substances with different mass or merging firms of different sizes in the same industrial sectors

As for Scenario 2, mass of System 1 is fixed at 1 kg while mass of System 2 is allowed to vary from 0.1 kg to 10 kg to determine the effect of the relative masses of the two systems on exergy destruction. The first and second columns of Table 3 provide the mass of System 2 and mass ratio of Systems 1 and 2, respectively. For different mass ratios of Systems 1 and 2, the temperature of System 2 is varied between 400 K and 1000 K to determine the effect of System 2's varying temperature and the two systems' mass ratio on exergy destruction. The exergy destruction calculations are performed separately from 400 K to 1000 K

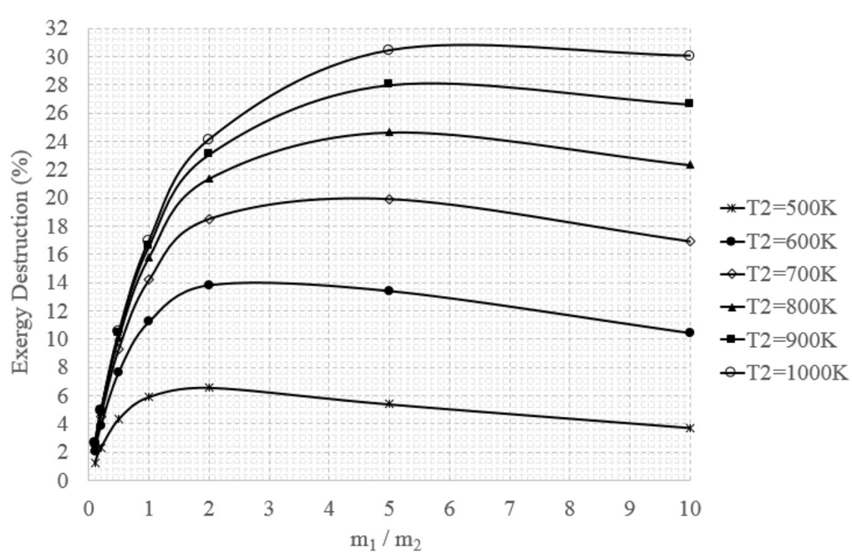

Fig. 3. Exergy destruction in percentage versus the ratio of mass 1 to mass 2.

Table 4
Exergy destruction (%) with respect to the changing ambient temperature of the mixture replicated at various internal temperatures of System 2 between 400 K and 1000 K.

Ambient of System 2[a] (K)	Exergy destruction (%) when T_2 =						
	400 K	500 K	600 K	700 K	800 K	900 K	1000 K
300	0.00	5.92	11.24	14.18	15.76	16.58	16.96
350	59.65	37.15	32.27	30.38	29.12	28.05	27.08
400	100.00	74.76	57.18	48.80	43.87	40.45	37.85
450	69.54	100.00	83.51	68.97	59.88	53.74	49.25
500	14.72	68.51	100.00	88.53	76.46	67.66	61.19

[a] The ambient of mixture is accepted to be same as the ambient of System 2.

for System 2 with 100 K increments at changing mass ratio (m_1 to m_2) values of 1/10 to 10.

Each curve in Fig. 3 gives exergy destruction of the mixture at a different temperature of System 2 for changing mass ratios of the two mixing systems based on the computations of Table 3. The figure reveals that smaller mass ratios (i.e., m_1/m_2 = 0.5, 0.2 and 0.1) yield small exergy destructions indicating thermodynamically more efficient mixing processes. It also appears that the peak in exergy destruction is obtained approximately at a mass ratio of 2 when System 2's temperature is 500 K or 600 K. Furthermore, the peak in exergy destruction shifts from a mass ratio of 2 to 5 when System 2's temperature is 700 K, 800 K, 900 K or 1000 K. Thus, mixing two systems with an approximate mass ratio of 5 (the larger mass has lower temperature) at high temperatures (i.e., T_2 is > 600 K) of System 2 yields larger exergy destructions. Further increase in mass ratio (m_1/m_2 > 5) seems to cause exergy destruction values to decline slightly at System 2's temperatures of 700 K, 800 K, 900 K and 1000 K.

Overall, exergy destruction increases as the relative mass of the system with lower temperature increases in the mixture. However, the increase in exergy destruction is not permanent. After reaching a maximum value that also depends on the temperature of System 2 (an approximate value of 2 for low temperatures of System 2 and 5 for high temperatures of System 2), exergy destruction starts decreasing as the relative mass of the two systems continue to increase.

When two firms *with different cultures, strategies or knowledge bases* merge, some exergy is always lost in this merge as stated in Propositions 1a and 1b. However, this exergy loss also changes with the *relative sizes of the two firms*. The exergy loss is lowest when the firm at lower state (in terms of knowledge base, expertise and etc.) is much smaller in size than the firm at higher state. The exergy loss is maximum when their relative sizes are in the middle range. This inflection point in exergy destruction rises with the increase in the differences of two firms' internal states.

Proposition 2. In merging two firms in the same industrial sectors at similar prior ambient conditions, the exergy loss due to merging is lowest when the firm with higher knowledge base is much larger in size than the one with lower knowledge base.

3.2.3. Scenario 3: mixing same substances with same mass at different ambient states or merging firms of similar sizes in the same industrial sectors from different countries

An exergy of a system is evaluated based on the system's ambient (i.e., environment or surrounding) conditions. In other words, the magnitude of a system's exergy is directly related to an ambient state. For example, a system would have a zero exergy if ambient state is same as the system's internal state. As for computations of Scenario 3, System 1 is initially kept at 400 K internal temperature with a 300 K ambient condition. Both systems have same mass of 1 kg. Table 4 provides values for exergy destruction of the mixing process between System 1 and 2 at varying ambient temperatures of System 2.

In all computations, the mixture is assumed to occur at an ambient temperature which is same as the ambient temperature of System 2. The ambient temperature of System 2 is varied between 300 K and 500 K with increments of 50 K to observe the effect of System 2's ambient temperature (which also becomes the mixture's ambient temperature)

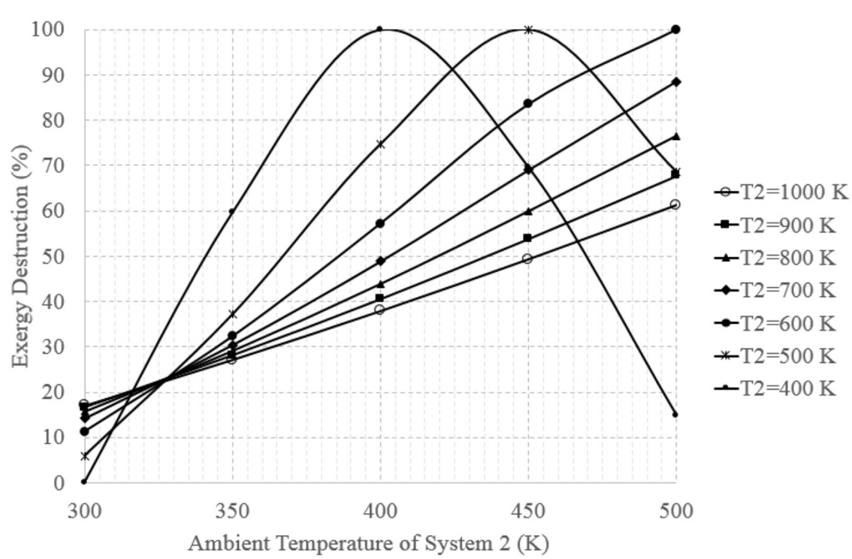

Fig. 4. Exergy destruction due to mixing versus the ambient temperature of System 2.

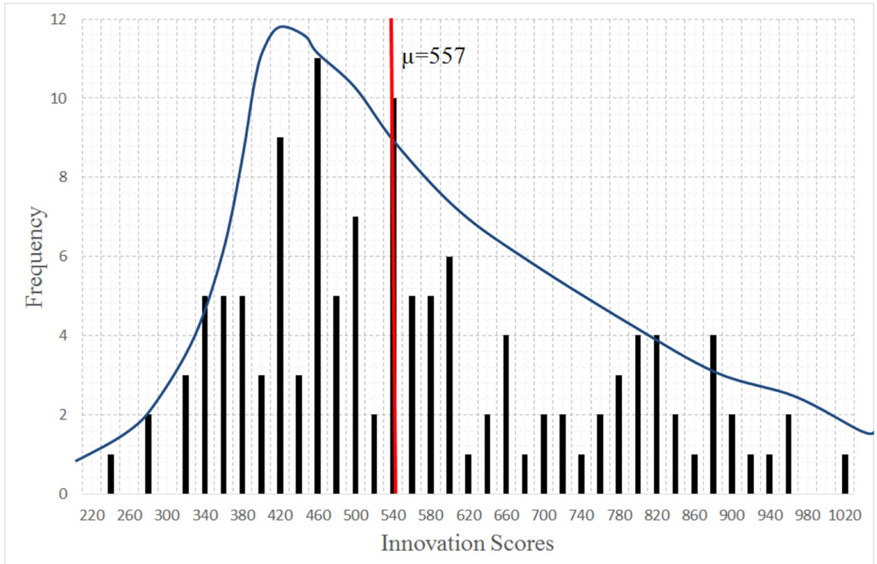

Fig. 5. Frequency distribution of transformed global innovation scores of 127 economies around the world (2017 GII scores).

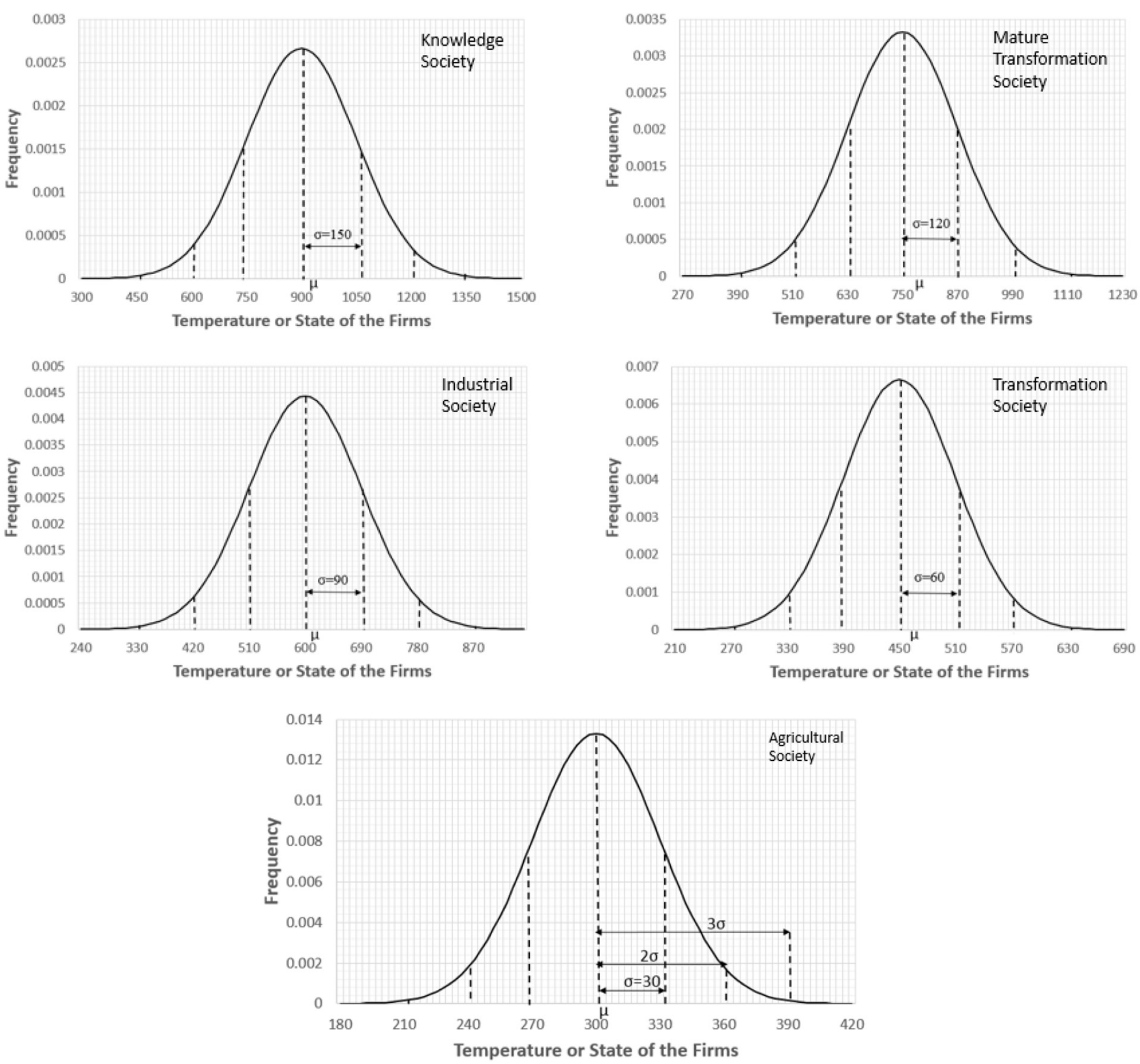

Fig. 6. The hypothetical (normal) distribution of all firms in a given country of a specific development phase.

on exergy destruction. While the ambient temperature of System 2 is given in the first column of Table 4, exergy destruction of the mixture is replicated for different internal temperatures of System 2 for which T_2 is varied from 400 K to 1000 K with a 100 K increment as given in the rest of the columns of Table 4.

Each curve in Fig. 4 corresponds to a different internal temperature of System 2 and illustrates exergy destruction due to mixing in terms of changing ambient temperature of System 2. Two main conclusions can be drawn from these plots. First, for a given internal temperature of System 2, exergy destruction increases with the increasing ambient temperature of System 2 (also the ambient for the mixture) where it reaches a peak value of 100% when internal temperature of the mixture becomes equal to the ambient temperature.

For example, 1 kg of System 1 at 300 K and 1 kg of System 2 at 500 K would have a 400 K of mixing temperature. Thus, when the ambient temperature is 400 K for the mixing temperature of 400 K, exergy destruction hits 100% indicating that mixing system cannot be utilized for any potential for work. While exergy destruction is maximum (100%) at this specific ambient temperature, the exergy destruction changes direction towards a decreasing state with the increase in the ambient temperature of the mixture as the bell curve shape indicates. Further increases in ambient temperature result in sharp decreases in exergy destruction. The decrease in exergy destruction from this point on is due to the fact that there exists potential energy for work when there occurs a difference in temperatures between the ambient and the system.

Second conclusion is on the effect of the internal temperature of System 2 on the relation between exergy destruction due to mixing and the ambient temperature. At lower ambient temperatures, as the difference in internal temperatures between the two systems increase, exergy destruction increases as this is also supported through the Proposition 1b of the first Scenario. However, at higher ambient temperatures (of nearly 325 K or larger), the increase in the difference between internal temperatures of the two systems result in lower exergy destructions. Thus, when the merging takes place at higher ambient temperatures, a higher internal temperature of System 2 is desired for more efficient mixing of the two systems.

In order to associate the physical states of Scenario 3 to the process of mergers and acquisitions, we first elaborate on how and with what measures the ambient in physical systems could be defined in the context of countries next. Then, we posit three propositions associating the relatedness between the merging firms and the ambient conditions of firms before and after merging on post-merger performance.

3.2.4. Different ambient states or country differences

The prior environmental conditions of the merging firms as well as the physical location (i.e., country that the merger takes place) of the newly formed organization might impact the post-performance of mergers. In order to get a proxy for the environmental conditions of the merging firms, we refer to the Global Innovation Index (GII) scores of 127 economies (Dutta et al., 2017). The data for global innovation scores in 2017 are provided in Table A1 of the Appendix A. Multiplying the scores with a constant (i.e., 15) transform to values that are very close to the selected temperatures of the scenarios that are discussed here as shown in Fig. 5. The average transformed scores is 557 with an overall distribution similar to a bell-shaped curve which is skewed to the right.

Using the distribution of global innovation scores of countries in Fig. 5, we attempt to classify countries according to innovation levels in five different phases of development across time that are agricultural society, transformation society, industrial society, mature transformation society or knowledge society (Alsan and Oner, 2004). Associating the development levels of countries (*or state of knowledge intensities or innovation levels*) with the ambient temperatures of physical systems, the distribution of the state of firms in a given country of a specific development phase could be hypothesized as a normal distribution[3] as shown in Fig. 6. In the first plot of Fig. 6, the underlying country is assumed to be in a development phase of “knowledge society” with a mean temperature of 900 K representing the average states of knowledge intensities of firms in that country. The average temperatures of the other phases of development could be posited as 750 K, 600 K, 450 K, and 300 K for mature transformation, industrial, transformation and agricultural societies, respectively.

Now, consider two firms of same size where one resides in a low state country such as one of the countries in transformation society (see Fig. 6) whose state is above the country average. Let the state of the firm and country represent the knowledge-base of the firm and the knowledge (or innovation) level of the country, respectively. Assume the two firms merge in the country where the second firm resides in and we explore the effect of the second firm's country specific factors (i.e., country's innovation level) on post-performance. As the second country's state of innovation improves, the exergy loss due to merging increases. The exergy loss is maximum when the merged organization's knowledge base happens to be same as the average knowledge (innovation) level of the country where the merge takes place. The newly merged organization being equivalent to the average firm in the country cannot compete in the market with the existing strategic and cultural incompatibility issues that it needs to deal because of the merging. Thus, in merging firms coming from countries of different states, it is better to allow the merge to take place in the country with a lower state of knowledge. In that case, the exergy loss due to merging would be smaller since the newly formed organization would be at higher states of knowledge than the average state of the country or region that it resides in.

Proposition 3a. In merging two firms of same size in the same industrial sectors coming from regions with different regional states (knowledge intensities or innovation levels) in the region where the firm with higher internal state resides in, the exergy loss due to merging increases as the state of the region that the merging takes place improves.

Another crucial observation could be made based on this scenario of merging firms that is given above. When two firms of same size merge, the overall performance of the newly formed organization decreases as the difference between the internal states of the merging firms increase as stated in Proposition 1b. This observation is valid when these two firms merge in a country with lower levels of state in terms of knowledge intensity or innovation levels. However, the situation changes conversely when the firms merge in a country with higher levels of state such as a knowledge or mature transformation society as given in Fig. 6. In that case, the exergy loss in the overall performance of the merged organization will be lower as the difference in initial states of the two firms increase. Thus, when the second firm resides in a country with high average states in knowledge intensities and the merging takes place in this region, the exergy loss due to merging decreases with the increase in the initial levels of knowledge-base of the second firm. Because of the higher knowledge-base of the second firm, the merging organization would do better in the market of firms all with high states of knowledge.

Proposition 3b. Consider two firms of same size in the same industrial sectors coming from regions with different states merge in the region where the firm with higher internal state resides in. Let the average state of the region that the merging takes place be low. Then, the

[3] The normal distribution assumption for the distribution of global innovation scores at country level could be attributed to both Fig. 5 and other economic efficiency measures that possess the characteristics of normal distribution. As an example, Total-factor productivity (TFPQ) distributions of selected countries (India, China and USA) are shown to be distributed in a way that is close to normal distribution as given in Appendix B based on the study of Hsieh and Klenow (2009).

overall loss in the post-performance due to merging increases as the difference in internal states of the two firms increase.

Proposition 3c. Consider two firms of same size in the same industrial sectors coming from regions with different states merge in the region where the firm with higher internal state resides in. Let the average state of the region that the merging takes place be high. Then, the overall loss in the post-performance due to merging decreases as the difference in internal states of the two firms increase.

4. Discussion

Mergers and acquisitions have been a long-running problem in the field of business and management as most mergers and acquisitions either do fail or result in poor performance (Cartwright and Schoenberg, 2006; Haucap and Stiebale, 2016; King et al., 2004; Prabhu et al., 2005). While there is an extensive amount of research on the reasons of failure, the findings of such studies do not converge to a robust theory of what motivates and makes a merger or acquisition a success. This study attempts to explore the issue of high failure rates in mergers and acquisitions using the fundamental laws of thermodynamics.

Linking the process of mixing in physical systems to merging in business, three propositions are developed based on the thermodynamic analyses of the mixing processes. The first and second propositions emphasize the importance of cultural or strategic relatedness in boosting the effectiveness of the merging process while the third proposition evaluates the loss of useful work in mergers from the viewpoint of contextual factors.

The first proposition states that merging two firms of similar sizes always result in a loss of exergy such that the exergy (or the potential to do work) of the newly formed firm would be lower than the sum of the exergies of these firms before merging. The exergy loss is even more as such two firms are more strategically or culturally incompatible. When the relative sizes of the firms differ, the exergy loss due to merging will be lower when the firm with higher knowledge base is relatively larger in size than the one with lower knowledge base. Thus, both propositions reflect to the findings in management and business literature on the importance of strategic similarity and cultural fit as the critical premerger success factors of more effective mergers and acquisitions (Chatterjee, 1986; Weber, 1996). "*Dancing to the same music using similar steps*" is the key to the success in merging as Makri et al. (2010) portray the importance of scientific and technological similarity in the combined firm's invention performance.

The third proposition on another hand puts forward the importance of contextual factors on output performance that is a much neglected aspect of mergers and acquisitions in the literature. In merging two firms of same size from different countries with different average levels of knowledge intensities, exergy loss due to merging increases as these two firms are merged in the country with higher average levels of knowledge intensity. Besides the country's ambient effect, the disparity in internal knowledge intensities of the two firms interact differently with the country's ambient conditions that the merging takes place. The exergy loss in the newly formed firm increases as the disparity in internal knowledge intensities of the two firms increase when the merging takes place in the country with low levels of knowledge intensities. The reverse effect would be observed when the country that the merging takes place has high levels of knowledge intensities.

Testing the propositions of this study is another endeavor requiring an in-depth empirical analysis of past mergers and acquisitions with respect to the firm, industry, and country-level post-performance factors that are designated in this study. However, we find it very interesting that our computations already match with some post- merger and acquisitions measures that are provided in the prior empirical studies. The average post-performance loss as measured by return on assets is found to be in the range of 0.55 to 2.25% in Rao-Nicholson et al. (2015). The difference in median pre- and post-acquisition performance is found to be between 0.65% and 1.73% based on three to four different performance measures by Martynova et al. (2007). Keeping in mind that such research are done based on empirical analyses of hundreds of mergers and acquisitions deals and the given median and average values of performance deteriorations, some companies may have even higher losses which could match with the range of exergy loss values given in the tables of our thermodynamic analyses.

These propositions have important implications for managers. Merging results in the loss of potential work or useful energy in the short run. However, some scenarios or situations are more preferable in minimizing this loss of exergy in merging. Two firms that are strategically fit or closer in culture are better matches for mergers. In merging a low state firm with a higher state firm in the country of the high state firm, it is better to choose a higher state firm from a lower state country. However, if such a merging would take place in the country of the high state firm where the average state of firms in that country is also high, then the higher the internal state of the firm the less the exergy loss is in merging. The higher state of the second firm would thus form higher barriers in competition with high profile actors in the market in the case of merging.

Drawing analogies between the parameters of a physical system and firm-specific factors in business is a challenging one. While relating the mass of a substance to a firm's size is relatively straightforward (although the operationalization of the construct presents different issues), linking temperature of a physical system to the knowledge base of a firm is prone to further discussion. In sum, motivated by the failures in mergers and acquisitions, this study provides a framework to link thermodynamics to management science. We develop three propositions for other scholars to further work on it and convert these propositions to measurable hypotheses. From this point on there exists various avenues for future research including adding other parameters of a physical system that interact with temperature and size by finding their correspondences in business, building research hypotheses, and testing them with real data.

4.1. Limitations[4]

As is well known in the modeling theory, "*All models are wrong; some models are more useful*" (Box and Draper, 1987). This study attempts to develop such a model starting with the idea that merging companies in the same industrial sectors can be resembled to mixing same substances in physical systems leaning on the possibility of an underlying grain of conceptual truth in the starting idea. Although the attempt to explain merger failures in thermodynamic terms may at first sight seem unconvincing, the issue of merger failures is dealt with a deductive reasoning in the sense that the fundamental laws of thermodynamics are applied to a specific phenomenon in business. Thus, the underlying conceptual model of this study forms the first building block of a long-run research marathon involving research complementing each other at conceptual, theoretical and empirical levels.

When it comes to the modeling assumptions and states of the conceptual model of a complex system of merging, thermodynamics discusses states. All the way to form a holistic dynamic model of the system, firms of different specializations, capabilities and assets along with various motivations for mergers certainly need to be built into the model. This study thus starts with variables such as size, knowledge base, culture or other firm-specific characteristics as the

[4] We are grateful for the useful comments of an anonymous referee which made us to incorporate this sub-section of Limitations to further acknowledge the constraints of this study.

representative states of temperature, mass and ambient conditions in physical systems which can be relaxed in future studies. Besides, we plan to delve into the empirical data of the prior studies in the literature to test the propositions of this study and future models as a continuation of the underlying research program that this study is based on.

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Appendix A. Data on global innovation scores of 127 countries around the world based on global innovation index (GII), 2017

Table A.1
Global innovation scores of 127 economies.

Economy	Rank	Score	Transformed score[a]
Switzerland	1	67.7	1015.5
Sweden	2	63.8	957
Netherlands	3	63.4	951
United States of America	4	61.4	921
United Kingdom	5	60.9	913.5
Denmark	6	58.7	880.5
Singapore	7	58.7	880.5
Finland	8	58.5	877.5
Germany	9	58.4	876
Ireland	10	58.1	871.5
Republic of Kora	11	57.7	865.5
Luxembourg	12	56.4	846
Iceland	13	55.8	837
Japan	14	54.7	820.5
France	15	54.2	813
Hong Kong (China)	16	53.9	808.5
Israel	17	53.9	808.5
Canada	18	53.7	805.5
Norway	19	53.1	796.5
Austria	20	53.1	796.5
New Zealand	21	52.9	793.5
China	22	52.5	787.5
Australia	23	51.8	777
Czech Republic	24	51	765
Estonia	25	50.9	763.5
Malta	26	50.6	759
Belgium	27	49.9	748.5
Spain	28	48.8	732
Italy	29	47	705
Cyprus	30	46.8	702
Portugal	31	46.1	691.5
Slovenia	32	45.8	687
Latvia	33	44.6	669
Slovakia	34	43.4	651
United Arab Emirates	35	43.2	648
Bulgaria	36	42.8	642
Malaysia	37	42.7	640.5
Poland	38	42	630
Hungary	39	41.7	625.5
Lithuania	40	41.2	618
Croatia	41	39.8	597
Romania	42	39.2	588
Turkey	43	38.9	583.5
Greece	44	38.8	582
Russian Federation	45	38.8	582
Chile	46	38.7	580.5
Viet Nam	47	38.3	574.5
Montenegro	48	38.1	571.5
Qatar	49	37.9	568.5
Ukraine	50	37.6	564

(*continued on next page*)

Table A.1 (*continued*)

Economy	Rank	Score	Transformed score[a]
Thailand	51	37.6	564
Mongolia	52	37.1	556.5
Costa Rica	53	37.1	556.5
Republic of Moldova	54	36.8	552
Saudi Arabia	55	36.2	543
Kuwait	56	36.1	541.5
South Africa	57	35.8	537
Mexico	58	35.8	537
Armenia	59	35.7	535.5
India	60	35.5	532.5
TFYR Macedonia	61	35.4	531
Serbia	62	35.3	529.5
Panama	63	35	525
Mauritius	64	34.8	522
Colombia	65	34.8	522
Bahrain	66	34.7	520.5
Uruguay	67	34.5	517.5
Georgia	68	34.4	516
Brazil	69	33.1	496.5
Peru	70	32.9	493.5
Brunei Darussalam	71	32.9	493.5
Morocco	72	32.7	490.5
Philippines	73	32.5	487.5
Tunisia	74	32.3	484.5
Islamic Republic of Iran	75	32.1	481.5
Argentina	76	32	480
Oman	77	31.8	477
Kazakhstan	78	31.5	472.5
Dominican Republic	79	31.2	468
Kenya	80	31	465
Lebanon	81	30.6	459
Azerbaijan	82	30.6	459
Jordan	83	30.5	457.5
Jamaica	84	30.4	456
Paraguay	85	30.3	454.5
Bosnia and Herzegovina	86	30.2	453
Indonesia	87	30.1	451.5
Belarus	88	30	450
Botswana	89	30	450
Sri Lanka	90	29.9	448.5
Trinidad and Tobago	91	29.7	445.5
Ecuador	92	29.1	436.5
Albania	93	28.9	433.5
Tajikistan	94	28.2	423
Kyrgyzstan	95	28	420
United Republic of Tanzania	96	28	420
Namibia	97	27.9	418.5
Guatemala	98	27.9	418.5
Rwanda	99	27.4	411
Senegal	100	27.1	406.5
Cambodia	101	27	405
Uganda	102	27	405
El Salvador	103	26.7	400.5
Honduras	104	26.4	396
Egypt	105	26	390
Plurinational State of Bolivia	106	25.6	384
Mozambique	107	24.5	367.5
Algeria	108	24.3	364.5
Nepal	109	24.2	363
Ethiopia	110	24.2	363
Madagascar	111	24.2	363

(*continued on next page*)

Table A.1 (*continued*)

Economy	Rank	Score	Transformed score[a]
Cote dIvoire	112	24	360
Pakistan	113	23.8	357
Bangladesh	114	23.7	355.5
Malawi	115	23.5	352.5
Benin	116	23	345
Cameroon	117	22.6	339
Mali	118	22.5	337.5
Nigeria	119	21.9	328.5
Burkina Faso	120	21.9	328.5
Zimbabwe	121	21.8	327
Burundi	122	21.3	319.5
Niger	123	21.2	318
Zambia	124	20.8	312
Togo	125	18.4	276
Guinea	126	17.4	261
Yemen	127	15.6	234

[a] Transformed score is the global innovation score multiplied by a constant (i.e., chosen as 15 here) to match the scores to appropriate temperatures in physical systems.

Appendix B. Total-factor production curves across different countries*

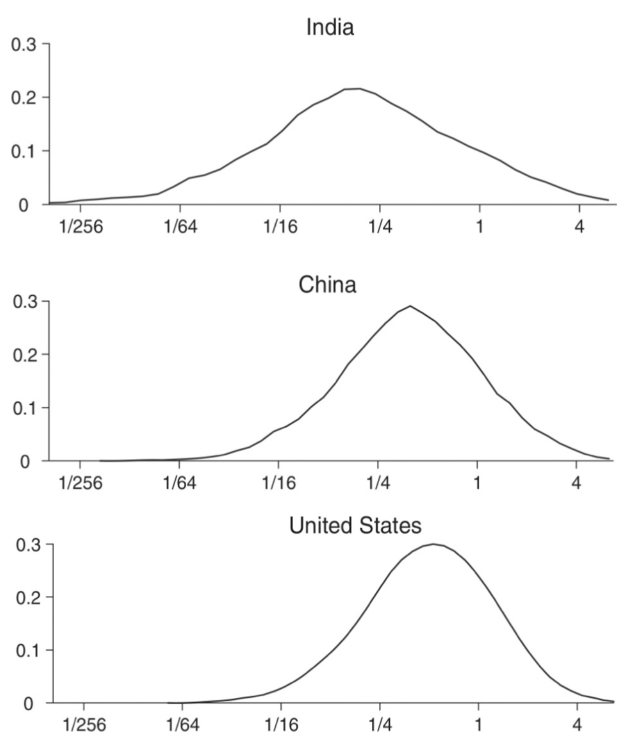

Fig. B.1. Distribution of TFPQ.
*Source: Fig. 1 in Hsieh and Klenow (2009).

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Gökçen Arkalı Olcay is an Assistant Professor at the School of Management at İstanbul Sehir University. She received her B.S. in Electrical Engineering from Bilkent University, and her M.S. and Ph.D. degrees in Operations Management from the University of Texas at Dallas. Her research interests include empirical research in operations management, innovation management, and R&D management. She teaches courses on Operations Management, Statistics, Statistical Analysis, Business Research and Quantitative Management.

Dr.-Eng. M. Atilla Öner is Professor of Technology and Operations Management in the Department of Business Administration and managing director of Management

Application and Research Center at Yeditepe University. His research interests are foresight methodology, technology road mapping, R&D management and technology management. He supervises MS/MBA and PhD theses on national innovation systems, pilot national (sectoral) foresight studies and system dynamic modeling of R&D management, project management and public policy issues. He is an associate editor of *Technological Forecasting and Social Change* and serves on the editorial board of *Foresight*, *Futures*, *International Journal of Innovation and Technology Management* and *Science, Technology and Development*.

Ali Bahadır Olcay received his B.S., M.S., and Ph.D. degrees in Mechanical Engineering from Middle East Technical University, Southern Illinois University Edwardsville and Southern Methodist University, respectively. He has worked as an adjunct professor at Southern Methodist University after his graduation. He joined the faculty of engineering at the University of Wisconsin in 2007. He also worked as a FEA/CFD consultant for Shaw Energy & Chemicals until his return to Turkey in 2010. He is currently a faculty member in the Department of Mechanical Engineering at Yeditepe University and his teaching and research interests are on thermal – fluid sciences.