
Errors in systems approaches

Kevin MacG. Adams* and Patrick T. Hester

National Centers for System of Systems Engineering,
Old Dominion University,
4111 Monarch Way Suite 406,
Norfolk, Virginia 23508 USA
E-mail: kmadams@odu.edu
E-mail: pthester@odu.edu
*Corresponding author

Abstract: Understanding and treating problems in complex systems, independent of the systems construct (i.e., socio-technical systems or socio-ecological systems), dictates the use of a formal systems approach. The systems approach may be methodological, a method, or a technique, but in each case it involves the imposition of order that ranges from the philosophical to the procedural. Independent of the philosophical construct or procedural rigor used in addressing the complex systems problem is the opportunity to commit a number of errors as part of the systems approach. This paper will discuss six classifications for problem solving errors that may be experienced during the application of a systems approach when understanding and treating complex systems problems.

Keywords: systems approaches; errors; error types.

Reference to this paper should be made as follows: Adams, K.M. and Hester, P.T. (2012) 'Errors in systems approaches', *Int. J. System of Systems Engineering*, Vol. 3, Nos. 3/4, pp.233–242.

Biographical notes: Kevin MacG. Adams is a Principal Research Scientist at the National Centers for System of Systems Engineering (NCSOSE), USA. He retired from the United States Navy in 1996 after 25 years of service. He received his PhD in Engineering Management and Systems Engineering from Old Dominion University in 2007.

Patrick Hester is an Assistant Professor of Engineering Management and Systems Engineering and Chief Scientist at the National Centers for System of Systems Engineering at Old Dominion University, USA. He received his PhD in Risk and Reliability Engineering from Vanderbilt University in 2007.

1 Introduction

Russell Ackoff (1919–2009) used the terms *machine-age* and *systems-age* to refer to eras that were concerned with two different types of systems. The machine-age was concerned with simple systems, and the systems-age is concerned with complex systems. Table 1 contrasts the most basic characteristics of the machine and systems ages (Ackoff, 1974; 1999).

Table 1 Ackoff's machine-age and systems-age characteristics

<i>Characteristic</i>	<i>Machine age</i>	<i>Systems age</i>
System Type	Simple	Complex
Boundary	Closed	Open
Elements	Passive parts	Purposeful parts
Observable	Fully	Partially
Method of understanding	Scientific method of reductionism	Cannot use reductionism

In addition to the characteristics displayed in Table 1, a complex system can be differentiated from a simple system by the rich contextual environment that is present in all complex systems. The inclusion of context introduces the *messy* situations that are predominant in human organisational endeavours. Ackoff's (1979, p.100) definition of a mess and messes is:

Because messes are systems of problems, the sum of the optimal solutions to each component problem taken separately is not an optimal solution to the mess. The behavior of the mess depends more on how the solutions to its parts interact than on how they interact independently of each other. But the unit in OR is a problem, not a mess. Managers do not solve problems, they manage messes.

The bottom line is that *real world* complex systems problems must include a definition of human activity in the formulation, analysis, and solution of the problem. This is routinely accomplished through the use of one of a number of systems-based approaches (Jackson, 1991, 2000, 2003). However, none of these systems-based approaches explicitly addresses the errors that may be committed as part of the formulation, analysis, and solution to the problem being addressed by the approach.

Analytical and interpretational errors occur regularly during the formulation, analysis, and solution of systems problems. These errors are committed independent of method (e.g., qualitative or quantitative) and epistemological tradition (i.e., positivist or post-positivist). The errors, of both commission and omission, complicate solutions to these *wicked problems* (Rittel and Webber, 1973).

We intend to present a typology of errors derived from the extant literature and use this as a construct, to be included in systems approaches, for avoiding common errors during the formulation, analysis, and solution to *messy* or *wicked problems* encountered in modern, complex systems.

2 Typology of errors

There is not general agreement on a single taxonomy for errors. However, our review of the literature on errors has revealed that researchers from four of the 42 fields of science¹ have conducted inquiry with respect to errors typology. This classification includes six major sectors and 42 individual fields of science. Table 2 includes references from the relevant fields of science.

From a review of the research in Table 2 we have been able to construct a typology of six common errors encountered during the formulation, analysis, and solution to *messy* or *wicked problems* in modern, complex systems.

Table 2 Sectors and fields of science conducting inquiry on errors

<i>OECD classification</i>		<i>Reference</i>
<i>Sector</i>	<i>Field</i>	
Social sciences	Educational sciences	Betz and Gabriel (1978), Kaufman et al. (1986), Marascuilo and Levin (1970, 1976), Onwuegbuzie and Daniel (2003), Rosnow and Rosenthal (1989, 1991)
	Psychology	Games (1973), Kaiser (1960), Leventhal and Huynh (1996), Levin and Marascuilo (1972, 1973), Meyer (1991), Mitroff and Featheringham (1974), Mitroff (1998)
	Economics and business	Boal and Meckler (2010), Umesh et al. (1996)
Natural sciences	Mathematics	Kimball (1957), Mosteller (1948), Neyman and Pearson (1928a, 1928b, 1933), Tracz et al. (2005)

2.1 Type I and Type II errors

The extant literature on the Type I and Type II errors originated in the mathematics (e.g., statistics) field of science with Neyman and Pearson (1928a, 1928b, 1933). Statistics journals and associated textbooks have reported consistently on these errors. The basis has been on logical considerations in statistical inference; specifically, the traditional non-directional two-sided test. For this test there are only two possible errors:

- 1 deciding that there is a difference, when, in fact, there is no difference
- 2 deciding that there is no difference, when, in fact there is a difference (Kaiser, 1960).

These are classified, respectively, as Type I (α) and Type II (β) errors. Table 3 contains a matrix and definitions for the Type I and Type II errors framed in terms of the testing of a null hypothesis, H_0 .

Table 3 Type I and Type II errors

<i>Test result</i>	<i>Actual condition</i>	
	<i>H₀ True</i>	<i>H₀ False</i>
Reject H_0	Type I error (α) False positive	Correct action True positive
Fail to reject H_0	Correct decision True negative	Type II error (β) False negative

There are two classic examples from the medical world of the Type I (α) and Type II (β) error, based on the premise of H_0 being that a person does not have a disease:

- *Type I (α) error:* A medical test indicates a person has a disease that they do not actually have.
- *Type II (β) error:* A medical test indicates a person does not have a disease that they actually do have.

Both of these error types occur after the complex system problem has been analysed and formulated and the system solution is being devised.

2.2 *Type III error*

The extant literature on Type III (γ) errors also originated in statistics. Frederick Mosteller (1916–2006), one of the most eminent statisticians of the 20th century, reported:

In other words it is possible for the null hypothesis to be false. It is also possible to reject the null hypothesis because some sample O_i has too many observations which are greater than all observations in the other samples. But the population from which some other sample say O_j is drawn is in fact the right-most population. In this case we have committed an error of the third kind. (p.61)

This is commonly referred to as “the error associated with solving the wrong problem precisely” [Mitroff, (1998), p.15].

Type III errors normally occur during the analysis of systems problem, the phase in which the actual details surrounding the reported problem are exposed, validated and verified as part of the process of problem reformulation. Failure to reformulate the reported problem is the most common source for a Type III error.

The systems practitioner faced with a *reported problem* needs to act much like a physician. The physician listens to the symptoms reported by a patient, but does not accept the diagnosis of the patient. The physician cannot rely solely on the patient’s story and symptoms, but must gather empirical data by conducting tests, taking physiological measurements, and conducting a physical examination. The systems practitioner is in a similar professional relationship with the client that has a systems problem. Problem reformulation ensures that the scope of the problem is properly abstracted from the real-world and defined. The problem system must be adequately bounded, include empirical data of both the quantitative and qualitative types, and include an understanding of both the environment and relevant stakeholders:

The initial representation or conceptualization of a problem is so crucial to its subsequent treatment that one is tempted to say that the most important as well as most difficult issue underlying the subject of problem solving is precisely ‘the problem of how to represent problems. [Mitroff and Featheringham, (1974), p.383]

Failure to properly define the scope of the problem results in inadequate problem statements and is commonly referred to as “the error committed by giving the right answer to the wrong problem” [Kimball, (1957), p.134].

2.3 *Type IV error*

A review of the extant literature on Type IV (δ) errors shows that this discussion has taken place in psychology and the educational sciences. To our knowledge, the first mention of the Type IV error in the literature was by Marascuilo and Levin (1970). They define the Type IV (δ) error as:

A Type IV error is said to occur whenever a correct statistical test has been performed, but is then followed by analyses and explanations that are not related to the statistical test used to decide whether the hypothesis should or should not have been rejected. [Levin and Marascuilo, (1972), p.368]

The authors report that the source of Type IV errors are:

(1) researchers typically employ post hoc statistical procedures with an associated Type I error probability different from that of the omnibus interaction test; and (2) researchers typically define contrasts among cell means which confound interaction parameters with other parameters of the ANOVA model. [Marascuilo and Levin, (1976), p.61]

While the discussion of the interactions in ANOVA models has dominated most of the scholarly dialogue (Umesh et al., 1996; Kaufman et al., 1986; Rosnow and Rosenthal, 1989, 1991), we have chosen to treat the Type IV (δ) error at a higher level of abstraction. More succinctly, we view the Type IV (δ) error as “the incorrect interpretation of a correctly rejected hypothesis” [Marascuilo and Levin, (1970), p.398].

Boal and Meckler (2010) elaborate on the problems caused by a Type IV error as:

Acting to solve a problem, be it the right problem or the wrong problem, can create other difficulties. Sometimes solutions are ‘iatrogenic,’ meaning that they create more, or bigger problems than they solve. Faced with such a possibility the decision maker should thoroughly examine all the potential system effects, and perhaps refrain from action.

In the case that it was an attempted solution to the right initial problem, one important problem is now replaced by another, perhaps worse problem. (p.333)

Thus, even though the problem has been correctly identified, the action identified to resolve the problem is incorrect. Further, there is potential in this situation for the identified problem solution to exacerbate the problem.

This type of error also has a medical analogy. In this case, the physician commits a Type IV (δ) error with the “correct diagnosis of an ailment followed by the prescription of a wrong medicine” [Marascuilo and Levin, (1970), p.398]. In extreme cases, incorrect prescriptions could lead to severe sickness or even death for the patient. The systems practitioner is prone to committing this error. The most typical instance is when the practitioner has properly reformulated and defined the client’s problem and then applies an improper solution methodology, method, or technique in an attempt to resolve this problem. Failure to match the solution method to appropriate solution of a problem has been an important subject in the systems literature (Jackson and Keys, 1984; Jackson, 1984; Adams and Mun, 2005).

2.4 *Type V error*

The field of cybernetics and the systems principle of homeostasis (Cannon, 1929) inform systems practitioners that systems have the ability to self-regulate to maintain a stable condition. Thus, some problems may solve themselves by simply allowing a natural order to restore itself. The converse of this is that many problems require intervention be solved and simply wishing for a problem to disappear on its own will not make it go away. There is a substantial risk in not acting when action is called for. Boal and Meckler (2010) discuss this sentiment as the Type V (ϵ) error:

Deciding to take no action, when no action is called for, is the correct solution. However, falsely believing that the problem will either solve itself or simply go away is an error of the 5th kind. Such errors allow the situation to linger, at best, or to fester and worsen requiring greater resources to solve. (p.334)

This error can also be explored through a medical analogy. In this case, a physician commits a Type V error when correctly diagnosing ailment and failing to take corrective action with respect to the patient's condition on the belief that the ailment will simply go away on its own.

There are many causes of a Type V error. Failure to achieve consensus among relevant stakeholders (e.g., the doctor and the patient do not agree on treatment options) may lead to inaction due to the lack of a singular prevailing option. Additionally, a simple lack of understanding of the root cause of a particular problem may lead to the inability of stakeholders to envision a plausible scenario for solving the problem at hand. Finally, stakeholders may fear worsening the problem by interfering with the underlying system. While this is a valid concern, it is often the case that inaction leads to more dire consequences than action.

2.5 Type VI error

A Type VI (ζ) error occurs when errors of Types I to V compound to create a larger, more complex problem than originally encountered. Boal and Meckler (2010) elaborate on the nature of Type VI errors:

When a Type VI error is made, the resulting problem may no longer be recognizable in its original form. The problems are not easily diagnosable, the resources and choices available become less sufficient or desirable, the solution is not readily apparent, and the solution not so attainable. (p. 336)

These problems become *wicked* (Rittel and Webber, 1973) as opposed to problems denoted as *tame* by Boal and Meckler (2010). They contrast the two problem types as:

Tame problems may be very complex, but they are solvable such as sending a man to the moon. It was a very complex problem, but the individuals could agree upon the definition of the problem and a solution could be found. Wicked problems are ones for which either the problem cannot be defined or no agreement on the solution can be found. (pp.336–337)

It is Type VI errors that we must truly be concerned about. Given that we are already talking about the analysis of complex systems problems, additional complexity introduced by committing a Type VI error, or what we term a *system of errors* to connote a correlation with Ackoff's (1974, p.100) messes (complex systems) as 'systems of problems', makes the problem intractable and unsolvable. Continuing with the theme of medical problems, a Type VI error can be conceived as one that first involves a physician diagnosing an incorrect problem for a patient, perhaps due to incorrect information provided by the patient (thus committing a Type III error). Let us suppose for the sake of argument that the patient is uninterested in receiving a true diagnosis of his symptoms as he fears grave news from the physician, so he downplays his symptoms. Given this incorrect (and underemphasised) problem, the physician decides to take no action to a problem otherwise requiring action (thereby committing a Type V error). His reasoning, based on the information he is received, is that the problem will go away on its own. The problem, untreated, worsens, thereby resulting in an inoperable condition, such as the progression of a benign cancer to a stage at which treatment is unavailable. Clearly, this *system of errors* has exacerbated the original in a form unimaginable by the original stakeholders (i.e., the patient and physician).

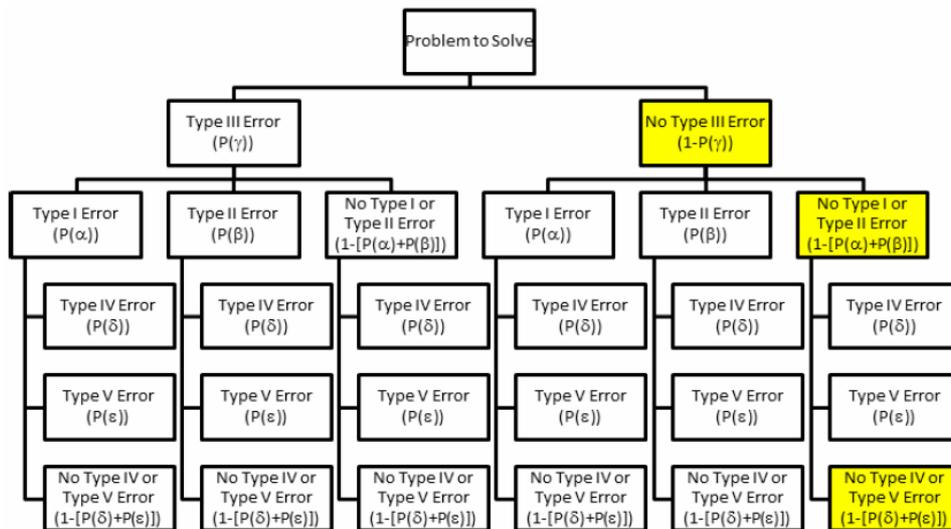
3 Discussion

We have described six classifications for problem solving errors that may be experienced during the application of a systems approach when understanding and treating complex systems problems. A typology of the six systems errors is presented in Table 4.

Table 4 Typology of systems errors

Error	Definition	Issue
Type I (α)	Rejecting the null-hypothesis when the null-hypothesis is true.	False positive
Type II (β)	Failing to reject the null-hypothesis when the null-hypothesis is false.	False negative
Type III (γ)	Solving the wrong problem precisely.	Wrong problem
Type IV (δ)	Inappropriate action is taken to resolve a problem as the result of a correct analysis.	Wrong action
Type V (ϵ)	Failure to act when the results of analysis indicate action is required.	Inaction
Type VI (ζ)	An error that results from a combination of the other five error types, often resulting in a more complex problem than initially encountered.	System of errors

Figure 1 Tree depiction of systems errors (see online version for colours)



A problem can be conceived as requiring three consecutive phases: formulation, analysis, and solution. Each of these phases is prone to a different set of errors. Formulation is prone to Type III errors, analysis to Type I or II errors, and solution to Type IV or V errors. In order for a problem to be solved correctly, all of these errors must be avoided. Thus, first the Type III error must be overcome; that is, the correct problem to be solved must be formulated. Then, both the Type I and Type II errors must be avoided by observing appropriate statistical practices, and making appropriate conclusions based on

these practices, during problem analysis. Finally, both the Type IV and Type V errors must be avoided by choosing the appropriate solution for a particular problem, given that the results of a problem demand action. This series of steps is shown graphically in Figure 1 in a manner adapted from Boal and Meckler (2010), but focused on the probabilities associated with particular paths available to the systems analyst. It is worth noting that Type VI errors are represented by the different error combinations presented in Figure 1 (i.e., a Type III error followed by a Type I error). Note that $P(\alpha)$, $P(\beta)$, $P(\gamma)$, $P(\delta)$, $P(\varepsilon)$, and $P(\zeta)$ represent the probability of a Type I-VI error, respectively.

Highlighted in Figure 1 is the only path through which a problem is solved that does not result in an error. This requires that no Types I to V (and by definition, Type VI) errors are committed. We can use this path to calculate the probability of a correctly solved problem as follows:

$$P(\text{solved problem}) = 1 - \left[\left[1 - P(\gamma) \right] \left[1 - (P(\alpha) + P(\beta)) \right] \left[1 - (P(\delta) + P(\varepsilon)) \right] \right]$$

While $P(\alpha)$ and $P(\beta)$ are straightforward quantities identified using statistical procedures, $P(\gamma)$, $P(\delta)$, and $P(\varepsilon)$ may prove to be difficult to estimate. However, this simple equation, understood at a conceptual level, shows that errors in a systems problem are serial; that is, a solution to a particular problem is only as strong as its weakest component, be it problem formulation, analysis, or solution. Any error decreases the overall probability of a correctly solved problem. Multiple errors substantially reduce the likelihood we will solve our problem correctly. Thus, the systems practitioner must be diligent in avoiding all of these error types or risk increasing the likelihood of unsuccessfully solving their problem.

4 Conclusions

Understanding and treating problems in complex systems dictates the use of a formal systems approach. Independent of the philosophical construct or procedural rigor used in addressing these complex systems problem is the opportunity to commit a number of errors as part of this approach. This paper discussed six classifications for problem solving errors that may be experienced during the application of a systems approach and presented a typology of these errors. The goal is to make practitioners aware of these errors so that they could avoid them during the formulation, analysis, and solution of a problem.

References

- Ackoff, R.L. (1974) 'The systems revolution', *Long Range Planning*, Vol. 7, No. 6, pp.2–20.
- Ackoff, R.L. (1979) 'The future of operational research is past', *The Journal of the Operational Research Society*, Vol. 30, No. 2, pp.93–104.
- Ackoff, R.L. (Ed.) (1999) 'Our changing concept of the world', *Ackoff's Best: His Classic Writings on Management*, pp.3–26, John Wiley & Sons, New York.
- Adams, K.M. and Mun, J.H. (2005) 'Towards a system of systems methodologies, once again', *Proceedings of the 26th National ASEM Conference: Organizational Transformation: Opportunities and Challenges*, pp.502–510, American Society for Engineering Management, Virginia Beach, VA.

- Betz, M.A. and Gabriel, K.R. (1978) 'Type IV errors and analysis of simple effects', *Journal of Educational Statistics*, Vol. 3, No. 2, pp.121–143.
- Boal, K. and Meckler, M. (2010) 'Decision errors of the 4th, 5th and 6th kind', in Nutt, P.C. and Wilson, D.C. (Eds.): *Handbook of Decision Making*, pp.327–348, John Wiley & Sons, West Sussex.
- Cannon, W.B. (1929) 'Organization for physiological homeostasis', *Physiological Reviews*, Vol. 9, No. 3, pp.399–431.
- Games, P.A. (1973) 'Type IV errors revisited', *Psychological Bulletin*, Vol. 80, No. 4, pp.304–307.
- Jackson, M.C. (1984) 'Beyond a system of systems methodologies', *Journal of the Operational Research Society*, Vol. 41, No. 8, pp.657–668.
- Jackson, M.C. (1991) *Systems Methodology for the Management Sciences*, Plenum Press, New York.
- Jackson, M.C. (2000) *Systems Approaches to Management*, Kluwer Academic, New York.
- Jackson, M.C. (2003) *Systems Thinking: Creative Holism for Managers*, John Wiley & Sons, Chichester.
- Jackson, M.C. and Keys, P. (1984) 'Towards a system of systems methodologies', *Journal of the Operational Research Society*, Vol. 35, No. 6, pp.473–486.
- Kaiser, H.F. (1960) 'Directional statistical decisions', *Psychological Review*, Vol. 67, No. 3, pp.160–167.
- Kaufman, N.J., Dudley-Marling, C. and Serlin, R.L. (1986) 'An examination of statistical interactions in the special education literature', *Journal of Special Education*, Vol. 20, No. 1, pp.31–42.
- Kimball, A.W. (1957) 'Errors of the third kind in statistical consulting', *Journal of the American Statistical Association*, Vol. 52, No. 278, pp.133–142.
- Leventhal, L. and Huynh, C. (1996) 'Directional decisions for two-tailed tests: power, error rates, and sample size', *Psychological Methods*, Vol. 1, No. 3, pp.278–292.
- Levin, J.R. and Marascuilo, L.A. (1972) 'Type IV errors and interactions', *Psychological Bulletin*, Vol. 78, No. 5, pp.368–374.
- Levin, J.R. and Marascuilo, L.A. (1973) 'Type IV errors and games', *Psychological Bulletin*, Vol. 80, No. 4, pp.308–309.
- Marascuilo, L.A. and Levin, J.R. (1970) 'Appropriate post hoc comparisons for interaction and nested hypotheses in analysis of variance designs: the elimination of Type IV errors', *American Educational Research*, Vol. 7, No. 3, pp.397–421.
- Marascuilo, L.A. and Levin, J.R. (1976) 'The simultaneous investigation of interaction and nested hypotheses in two-factor analysis of variance designs', *American Educational Research Journal*, Vol. 13, No. 1, pp.61–65.
- Meyer, D.L. (1991) 'Misinterpretation of interaction effects: a reply to Rosnow and Rosenthal', *Psychological Bulletin*, Vol. 110, No. 3, pp.571–573.
- Mitroff, I.I. (1998) *Smart Thinking for Crazy Times: The Art of Solving the Right Problems*, Berrett-Koehler Publishers, San Francisco.
- Mitroff, I.I. and Featheringham, T.R. (1974) 'On systematic problem solving and the error of the third kind', *Behavioral Science*, Vol. 19, No. 6, pp.383–393.
- Mosteller, F. (1948) 'A K-sample slippage test for an extreme population', *Annals of Mathematical Statistics*, Vol. 19, No. 1, pp.58–65.
- Neyman, J. and Pearson, E.S. (1928a) 'On the use and interpretation of certain test criteria for purposes of statistical inference', *Part I. Biometrika*, Vol. 20A, Nos. 1/2 pp.175–240.
- Neyman, J. and Pearson, E.S. (1928b) 'On the use and interpretation of certain test criteria for purposes of statistical inference', *Part II. Biometrika*, Vol. 20A, Nos. 3/4, pp.263–294.

- Neyman, J. and Pearson, E.S. (1933) 'The testing of statistical hypotheses in relation to probabilities a priori', *Mathematical Proceedings of the Cambridge Philosophical Society*, Vol. 29, No. 4, pp.492–510.
- OECD (2007) *Revised Field of Science and Technology (FOS) Classification in the Frascati Manual*, Organization for Economic Cooperation and Development, Paris.
- Onwuegbuzie, A.J. and Daniel, L.G. (2003) 'Typology of analytical and interpretational errors in quantitative and qualitative educational research', *Current Issues in Education*, Vol. 6, No. 2.
- Rittel, H.W.J. and Webber, M.M. (1973) 'Dilemmas in a general theory of planning', *Policy Sciences*, Vol. 4, No. 1, pp.155–169.
- Rosnow, R.L. and Rosenthal, R. (1989) 'Definition and interpretation of interaction effects', *Psychological Bulletin*, Vol. 105, No. 1, pp.143–146.
- Rosnow, R.L. and Rosenthal, R. (1991) 'If you're looking at the cell means, you're not looking at only the interaction (unless all main effects are zero)', *Psychological Bulletin*, Vol. 110, No. 3, pp.574–576.
- Tracz, S.M., Nelson, L.L., Newman, I. and Beltran, A. (2005) 'The misuse of ANCOVA: the academic and political implications of Type VI errors in studies of achievement and socioeconomic status', *Multiple Linear Regression Viewpoints*, Vol. 31, No. 1, pp.16–21.
- Umesh, U.N., Peterson, R.A., McCann-Nelson, M. and Vaidyanathan, R. (1996) 'Type IV error in marketing research: the investigation of ANOVA interactions', *Journal of the Academy of Marketing Science*, Vol. 24, No. 1, pp.17–26.

Notes

- 1 We use the internationally accepted Organization for Economic Co-operation and Development (OECD) (2007) structure of classification for the six major sectors and 42 individual fields of science.