ENTROPY IN ECONOMICS: ITS MEASUREMENT THROUGH PRIMARY DATA AND ITS USEFULNESS IN BUSINESS

Elias Sanidas
School of Economics, University of Wollongong

Abstract
Since Georgescu-Roegen's ("The entropy law and the economic process", 1971) pioneering work on entropy in economics, not many scholars have preoccupied themselves with this concept and its consequences. Recently some revival is taking place to link entropy and the business world (see for example "The entropy vector, connecting science and business" by Handscombe and Patterson, 2004).

Briefly entropy is the degree of disorder at some time for any system. For a closed system the natural tendency would be for entropy to keep increasing till final destruction. In the business world, entropy is also present and unless some actions are taken, any business will become more and more ineffective and eventually die. Sanidas ("The open system of four dynamic bio-socio-economic processes of the firm: the diamond of the black box", 2006) has introduced four processes ("processes of the black box, or PROBB) that are negentropic, in other words they can prevent entropy from increasing during all operations of a firm.

Based on Sanidas's work a questionnaire has been constructed and a survey was conducted with 120 firms in the marine industry in Australia. In this paper part of the results of this survey is presented with the aim to measure entropy in business. Thus, variables that denote waste directly or indirectly are some of the variables to correlate with all variables in the PROBB and inspect which such correlations are the strongest. The examination of these correlations together with some other analyses is providing us with some encouraging results as to the measurement of entropy. In turn such measurement will enable us to establish which areas are primary sources of inefficiencies. Obviously, the detection of these inefficiencies is necessary for firms to become more competitive and robust in their commercial and production activities.

Key words: *entropy, waste, measurement, firms*

Introduction

Since Georgescu-Roegen's (1966, 1971) pioneering work on entropy in economics[1], several scholars have preoccupied themselves with this concept and its consequences. Recently some revival is taking place to link entropy and the business world; see for example Handscombe and Patterson' s (2004) paper as a general and simple exposition of the issue; Khalil (2004) who made an overall critique of Georgescu-Roegen's work; Smith and Foley (2008) who rigorously demonstrated the links between entropy and economic general equilibrium theory; Ayres (1994) who related entropy to many aspects of information, economics, evolution, and progress. Briefly, entropy is the natural universal process according to which there is a tendency for wasting energy so that increasing disorder and decreasing efficient productive work takes place in a system unless some actions occur that slow down this process. Handscombe and Patterson (2004, p. 1) define entropy very simply as "the degree of disorder or chaos that exists or is created". Thus, "entropy in a closed system must remain constant or increase" (Moore, 2007, p. 38).

[1] A good summary of this author's significant work can be found in Maneschi and Zamagni (1997).

From Handscombe and Patterson, (2004), we can isolate some variables to represent entropy in business (see Table 1). Note that these variables although included in one of the three categories (columns in Table 1) can also be used in the other categories but in the opposite direction. Thus an entropy-increasing variable can also be an entropy-decreasing variable in a different context. A good example is leadership which can generate decisions that are either entropy-decreasing or the contrary. It would be useful to quote these authors for some of these variables.

> *Business plans provide a way of trying to think ahead in order to organize (i.e. minimize) disorder in the way that a business is developed (ibid, p. 134).*
>
> *A company's ability to change is determined by its vision multiplied by its leadership and resources, all divided by the corporate age (ibid, p. 20);* the corporate age is *the inertia to do with culture, attitude, procedures, practices (ibid, p. 20).*
>
> *Information must be considered as a negative term in the entropy of a system…We have only partial information and entropy measures the lack of information (ibid, p. 28).*
>
> *The entropy vector encourages us to realize that the lack of setting broad tolerances is as important as setting the specific objectives (ibid, p. 44.*
>
> *Experience curve, which is simply the continuous resetting of the entropy vector (ibid, p. 46).*
>
> *A lack of collaboration can be equated with entropy (ibid, p. 85).*

And so on.

Table 1 Entropy-related factors/variables in conducting business

Increasing entropy	**Decreasing entropy**	**Increasing or decreasing entropy**
Waste	Innovations	Culture
Inertia	Experience	Attitudes
Lack of information	Vision	Procedures
Decreasing constraints	Leadership	Risk taking thinking
Deregulation	Tolerance	
Lack of collaboration	Objectives	
Stress level	Production line	
Fatigue	Knowledge	
Conformity/convention	Links with outside	
Uncertainty	Planning	

The aim of this paper is to check whether these factors (and others) as seen in Table 1 are important indeed in a real case. We will use as a real case a sample of 80 firms[2] from the marine industry in Australia (the survey was conducted during 2006 and 2007). For this purpose, we need a theoretical model which will help us to properly analyse the above real case in order to detect any signs of entropy. Recently Sanidas (2005, 2006) has introduced a comprehensive model of describing and explaining a firm's dynamic path in the economy. This model includes –in a succinct way- all major factors that shape the firm's evolution in

[2] By now 120 firms have been surveyed but the extra 40 on top of the 80 are not included in the analysis of this paper due to time limitations.

growth. The theory of the firm is extended to encompass all types of opportunity costs and not just transaction costs. As a further extension to the transaction costs and capabilities development and as a synthesis of several related issues, Sanidas (2006) has introduced a complete system of 4 mutually exclusive, interdependent and negentropic[3] processes (PROBB) that fully describe the contents of the black box[4] of production (see Table 2). This model as Table 2 shows is a comprehensive summary of all elements that uniquely describe and explain the way firms are organized, managed and grow. These four PROBB are interdependent, although each PROBB contains unique elements that cannot belong to another PROBB.

The important point to notice in this Table 2 with the PROBB variables is that each one of them represents opportunity costs. Thus, the POC variables represent transaction (or friction) costs, the POS elements stand for strategic opportunity costs, the POW variables express wisdom costs and the POM factors generate kinetic costs. All these different types of opportunity costs contribute to the natural law of entropy. However, it must be reminded that the PROBB variables can be both entropy-increasing and entropy-decelerating depending on how they are used in a business context. This will also be the object of investigation in the present paper.

Table 2 The complete four processes of the black box (PROBB)

P O W	**P O S**	**P O M**	**P O C**
Process of wisdom	**Process of strategies**	**Process of movements**	**Process of contracts**
Power	**Survival**	**Infrastructure**	**Superstructure**
Ability and memory	Initiatives for action	Movement relations between the TIOP	Rules of the relations between the TIOP
Wisdom costs*	**Strategic costs**	**Kinetic costs**	**Transaction costs**
Purpose*: to decrease '**negative' * knowledge**	Purpose: to produce fewer **mistakes**	Purpose: to produce less **waste***	Purpose: to produce less **friction**
Potential energy	**Reaction energy**	**Kinetic energy**	**Friction energy**
Experience	Strategies	Timing	Contracts with employees*
Tacit knowledge	Everyday decisions*	Kinetic Procedures (e.g. in just-in-time)	Legal form of the firm
Education and training	Planning	Kinetic routines	Contracts with suppliers*
Culture and aesthetics	Vision	Layout	Contracts with customers
Information and data	Mission	Transport	Contracts with society
Competences and capabilities*	Objectives	Teamwork	Legal standards
R&D*	Attacks	Kinetic coordination (harmonization)	Accounting rules
Imitation	Defense	Implementation	Institutions
Innovations*	Inertias	Execution	Governance

[3] "Negentropic" means that the effect on entropy is negative, hence the underlying processes have the tendency to slow down increases in entropy or even to decrease entropy.
[4] The term "black box" was coined by Coase (1992), the Nobel Prize laureate who introduced transaction costs in economics.

Leadership*	Momentum	Kinetic organization*	Trust*
POW	**POS**	**POM**	**POC**
Techniques of analysis	Entrepreneurship*	Effort non-physical	Standards
Needs* (e.g. for exploration)	Domination and Exploitation	Effort physical*	Authority
Motivation*	Initiatives	Fatigue	Control
Cognitive capacity and attention	Inspiration for action	Cooperation (actual kinetic)	Opportunism
Bounded rationality: Subjectivity	Decision making*	Work satisfaction as a team	Supervision rules
Idiosyncrasy	Forecasting	Kinetic tasks	Incentives
Attitudes and beliefs*	Uncertainty	Ergonomics	Functions
Marketing intelligence*	Mistakes	Logistics	Autonomy
Sophistication	Policies	Problem solving*	Negotiations
Socio-Psychological states*	Organizational defensive routines*	Mechanisms of feedback*	Documentation
Explicit knowledge	Risk	Performance	Ownership rules
Design of products	Reactions to fortuitous events	*Ad hoc* non-routine movements	Informal rules
POW	**POS**	**POM**	**POC**
Operations research techniques	Readiness and emergence*	Operations research applications (e.g. PERT)	Conventions
Intuition*, impressions, perception*	Interpretation and judgment	Work rationalization (e.g. scientific	Conflict solutions
Organizational spirit* and capital	Sense making*	Location	Communications rules
Imagination* and Afflatus	Improvisations and Heuristics*	Projects	Status
Unconscious*	Expectations	Transfer	Hierarchy
Illusions*	Will		Form or structure of the firm (e.g. M-form)
Conception, insights			Equity
Subconscious and emotions*			
Utility versus virtue*			

*For the terms with an asterisk see Appendix 2 of Sanidas, 2006. Source: Sanidas (2006).

The remaining of the paper will be as follows. Section 2 will introduce methodology and present the results; and section 3 will discuss conclusions.

Methodology and results

The model PROBB contains about 150 variables out of which about 120 are directly related to the elements of Table 2 above, and the remaining are more performance or economics related. The former will be called the X, Y, Z, and W PROBB variables

corresponding to the four processes respectively (POS, POW, POM, and POC); whereas the latter will be called the V variables. They are:

V1: Customers dictate terms and requirements (the opposite of the 7-score Likert scale would be: we, the firm, dictate these terms)
V2: Suppliers dictate terms and requirements (as for V1)
V3: Rivals are weak (strong):
V4: Power we, the firm, have in dictating prices and/or quantities
V5: Low cost strategy (low, high)
V6: Low price strategy (low, high)
V7: Niche market strategy
V8: Product quality
V9: Product uniqueness
V10: Availability of large market for our product
V11: Adoption of technical innovations
V12: Creation of technical innovations
V14: Technology choice affected company operations (low, high)
V15: Company operations affected technology choice
V21: Sales growth in the last 5 years

These V variables represent the consequences of the importance and direction of all PROBB variables. Thus we would expect that some PROBB variables-for a given firm- are rather negative in their action towards the Vs. Those PROBB variables that are not well related to Vs -for a given firm- can be termed the potentially entropy increasing and those PROBB variables that are well related to Vs can be termed the potentially entropy decreasing.

First we can test the impact of each PROBB variable on the totality of the Vs. Second, later further below, we will test the impact of each PROBB variable on each individual V. Thus we first need a test that testifies the impact of a given PROBB variable on the totality of the V variables. Such a test is the Bartlett test of sphericity usually used in factor analysis. It shows how well all variables in a group are correlated with each other. It is calculated as a chi-square test. The way to use this test in our study is as follows: first we calculate the Bartlett chi-square for all V variables only. This value is 1789. Then we calculate the same test by adding to all V variables a PROBB variable. The increment in chi-square will obviously indicate how well the PROBB variable is correlated with all V variables together. According to the Bartlett test and the procedure just described, Table 3 shows the distribution of calculated chi-square for all PROBB variables.

Table 3 Bartlett test for the impact of each PROBB variable on all Vs

Value of chi-square	Absolute frequency of PROBB elements	Relative frequency	Cumulative frequency (%)
1880 (category A)	10	9.2	
1903 (category B)	10	9.2	18.3 (up to 1903)
1930	24	22.0	
1965	23	21.1	
2003	23	21.1	64.2 (1930 to 2003)
2035 (category C)	9	8.3	
2200 (category D)	10	9.2	17.4 (2035 to 2200)

Table 4 shows the lowest (A and B categories) and highest (C and D categories) performance (as chi-square) of individual variables in being correlated with the basic performance variables Vs (considered in their totality).

Table 4 Lowest and highest chi-square (Bartlett test) for PROBB variables

	A		**B**		**C**		**D**
x10	1872	x26	1903	x12	2011	x1	2039
x23	1875	y21	1885	x17	2031	x9	2046
z19	1861	y40	1902	y17	2030	x13	2124
z22	1846	z15	1887	z25	2013	y15	2109
z29	1861	z32	1890	z28	2014	y36	2040
z34	1869	z35	1903	z33	2004	y44	2063
z36	1876	w15	1892	w1	2031	z16	2051
w16	1862	w22	1890	w2	2012	w7	2042
w32	1850	w29	1889	w3	2027	w13	2076
w33	1862	w31	1882			w25	2045
average	*1863*		*1892*		*2019*		*2064*
median	*1862*		*1890*		*2014*		*2049*

Note: Categories A and B are the least related to the V variables hence they are the least-decreasing categories of entropy. Categories C and D are the most related to the Vs hence they are the most decreasing categories of entropy.

For the A category we have the following PROBB variables as seen in Table 4.

X10: inertia
X23: interpreting surroundings
Z19: achievement of production routines
Z22: well defined tasks that involve movements
Z29: fatigue
Z34: location
Z36: careful implementation of production operations
W16: status (hierarchy) hindering management
W32: management resolving conflict
W33: equity (vital/crucial)

An inspection of these PROBB variables shows that it makes sense that they are not well correlated with the group of V variables. Thus, for example, “inertia”, “fatigue”, “status”, and “conflict resolving” do not offer a substantial amount of information in promoting the Vs. Each one of these 10 PROBB variables is not capable in reducing or slowing down entropy and hence entropy will follow its natural tendency to increase.

For the B category we have the following PROBB variables as seen in Table 4.

X26: uncertainty
Y21: culture in company influencing relationships in the firm
Y40: accumulated knowledge or ad hoc processes enhancing innovations
Z15: frequency of usage of OR (operations research) methods
Z32: layout
Z35: harmonization/coordination of production activities
W15: demarcation of functions
W22: structure of firm (e.g. departmental) assisting management
W29: selfish staff more than expected by upper management
W31: staff negotiations with management

Whatever we said about the category A PROBB variables we can also say about these B category variables but to a lesser degree. In addition, for both A and B categories we can see that many of their corresponding PROBB variables are approximations or representations for entropy factors as mentioned in Table 1 above: uncertainty, inertia, lack of collaboration, and so on. This can be seen more precisely in Table 5.

Table 5 Correspondence between some entropy-related and PROBB variables (part 1)

Inertia	Lack of information	Decreasing constraints	Lack of collaboration	Stress level	Conformity	Uncertainty	procedures
X10	X23	W33	W29	Z29	Y21	X26	Z19
Z32	Z15		W31		W15	Y40	Z22
Z34			W32		W16		Z35
W22							Z36

For the C category we have the following PROBB variables as already indicated in Table 4.

X12: entrepreneurship versus cautious type of management
X17: exploring large markets to secure a large market share
Y17: marketing intelligence
Z25: non-routine versus routine activities (valuable)
Z28: monitoring physical efforts
Z33: using ergonomics
W1: detailed and rigorous contracts with employees
W2: detailed and rigorous contracts with suppliers
W3: detailed and rigorous contracts with customers

For the D category we have the following PROBB variables as already indicated in Table 4.

X1: using formal strategies
X9: defence in the market
X13: initiatives with far reaching consequences
Y15: mental and thinking capacities
Y 36: self-interest versus altruism of staff as a group
Y44: replication by other firms of your knowledge of products and services
Z16: using methods to rationalize work
W7: traditions and institutions of staff members
W13: company form (e.g. Pty) affecting functioning of the firm
W25: using and applying control measures

For both the C and D categories we can see that many of their PROBB variables are good proxies for the variables in Table 1 that are considered to reduce or slow down entropy. Thus, W1, W2, W3, W13, and W25 increase constraints on the system: this is exactly what a system needs in order to slow down entropy as was mentioned above regarding the variables of Table 1. In Table 6 we complete the correspondence between the PROBB variables of categories C and D and the variables affecting the slow down of entropy as per Table 1.

Table 6 Correspondence between some entropy-related and PROBB variables (part 2)

Increasing constraints	Experience	Leadership	Tolerance	Stress level	Production line	Knowledge	Links with outside	Planning
W1	W7	X12	Y36	Z28	Z16	Y15	Y44	X1
W2		X13	X9	Z33	Z25	Y17		X17
W3								
W13								
W25								

Table 7 shows the distribution of the four PROBB in terms of the four categories of entropy impact as described in Table 2.

Table 7 PROBB categories and entropy related intensity

Entropy category	**POS**	**POW**	**POM**	**POC**	**Total**
A: most increasing	2	0	5	3	10
B: increasing (less than in A)	1	2	3	4	10
Total A and B: increasing (or least decreasing)	**3**	**2**	**8**	**7**	**20**
C: decreasing	2	1	3	3	9
D: most decreasing (more than in C)	3	3	1	3	10
Total A and B: decreasing (or slowing down)	**5**	**4**	**4**	**6**	**19**
Grand total (A+B+C+D)	**8**	**6**	**12**	**13**	**39**

From Table 7 we can see that the POC is heavily represented in both the increasing and decreasing PROBB variables. The POM is only mostly present in the entropy-increasing categories. From the PROBB model viewpoint, this means that kinetic (POM) and friction (POC) energies are mainly responsible for affecting entropy in a substantial way.

Now we turn to the testing of the impact of each PROBB variable on each V variable separately. Thus it remains to see which PROBB variables are most correlated with the performance variables Vs. Table 8 shows the results.

Table 8 Significant correlations between PROBB variables and V variables

	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V14	V15	V21	total
X1				*							*		*	*	*	5
X2						*					*				*	3
X3				*			*							*		3
X4				*											*	2
X5				*											*	2
X6				*		*									*	3
X7					*		*		*		*	*				5
X8									*		*	*			*	4

X9				*			*		*		*	*			*	6
X10																0
X11	*		*													2
X12							*		*		*			*	*	5
X13			*	*			*	*	*		*	*		*	*	9
X14	*	*		*			*	*								5
X15	*				*				*		*		*	*		6
X16					*	*	*		*							4
X17				*					*	*		*				4
X18																0
X19				*			*				*		*	*	*	6
X20										*						1
X21		*		*		*							*	*	*	6
X22				*												1
X23		*														1
X24	*						*	*								3
X25			*	*									*	*		4
X26			*												*	2
X27			*				*		*		*	*			*	6
TOTAL POS	4	3	5	13	3	4	10	3	9	2	10	6	5	8	13	
	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**	**V11**	**V12**	**V14**	**V15**	**V21**	total
Y7				*					*		*	*		*		5
Y8	*				*	*										3
Y13		*	*													2
Y14					*											1
Y15				*		*	*		*	*	*	*			*	8
Y17							*		*		*	*				4
Y18	*						*									2
Y19				*			*		*		*	*				5
Y20						*	*		*							3
Y21														*		1
Y22					*			*	*							3
Y23						*			*							2
Y31						*										1
Y32									*					*		2
Y33							*		*				*			3
Y34			*			*			*							3
Y35	*								*							2
Y36			*			*										2
Y38							*	*	*	*						4
Y39		*			*									*		3

Y40	*						*									2
Y41												*	*			2
Y42			*													1
Y43							*		*					*		3
Y44	*		*		*			*	*	*	*			*		8
Y50						*			*						*	3
Y51								*	*				*			3
TOTAL POW	5	2	5	3	5	8	9	4	16	3	5	5	3	6	2	
	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**	**V11**	**V12**	**V14**	**V15**	**V21**	total
Z1		*									*	*				3
Z2						*		*								2
Z15																0
Z16			*				*			*		*				4
Z17				*								*				2
Z18				*												1
Z19			*					*								2
Z20																0
Z21						*				*						2
Z22																0
Z23							*	*								2
Z24									*		*	*		*		4
Z25		*			*	*	*						*	*		6
Z26																0
Z27					*											1
Z28		*				*	*	*			*					5
Z29																0
Z30															*	1
Z31	*	*					*		*		*	*				6
Z32																0
Z33			*	*				*		*						4
Z34		*														1
Z35							*							*	*	3
Z36							*	*						*		3
Z37			*	*											*	3
Z38			*	*				*								3
TOTAL POM	1	5	5	5	2	4	7	7	2	3	4	5	1	4	3	
	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**	**V11**	**V12**	**V14**	**V15**	**V21**	total
W1									*		*		*	*		4
W2		*	*	*												3
W3				*			*					*	*	*		5
W4	*			*						*						3

W5							*		*						*	3
W6			*				*				*			*		4
W7		*			*			*		*						4
W8		*		*			*				*	*		*		6
W9			*					*								2
W10		*			*	*				*					*	5
W11						*										1
W12		*									*	*			*	4
W13				*	*	*		*						*		5
W14			*						*	*		*				4
W15																0
W16																0
W17												*				1
W22								*							*	2
W23	*	*							*	*	*					5
W24				*			*				*	*	*	*	*	7
W25		*					*	*	*		*	*				6
W26						*			*							2
W27								*	*							2
W28					*			*								2
W29	*		*													2
W30						*										1
W31							*		*				*			3
W32																0
W33															*	1
TOTAL POC	3	7	5	6	4	5	7	7	8	5	7	7	4	6	6	
	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**	**V11**	**V12**	**V14**	**V15**	**V21**	total
GRAND TOTAL ALL PROBB	13	17	20	27	14	21	33	21	35	13	26	23	13	24	24	

Notes: (i) For the definition of the remaining PROBB variables see Appendix 1. The correlation coefficients are usually between 0.10 and 0.30.

In Table 8 we can see that some variables V are more correlated with PROBB variables than other variables V. Thus, for example, V9 (product uniqueness) is significantly correlated with 35 PROBB variables. Or V1 (customers dictate terms and requirements) are significantly only correlated with 13 PROBB variables, and so on. These differences can be used to measure the degree of negentropy. Georgescu-Roegen (1966, p. 76) mentions Boltzmann's formula: entropy = k log n, where k is a constant and n is the number of equivalent microstates. Handscombe and Patterson (2004, p. 38) use a simple example to demonstrate the meaning of Boltzmann's simplified formula: n can be for example 1 out of 5 (low entropy) possible patterns in an experiment or 1 out of 1000 (high entropy). Consequently in our case, an approximation of direct calculation of entropy would be for V7: entropy = k log 33/109 = -0.52k, or for V2: entropy = k log 17/109 = -0.81k. Thus, entropy for V2 is greater than entropy for V7 (by considering the absolute value), and so on.

In other words, the strategic/performance variable V2 is not sufficiently correlated with PROBB variables to guarantee low entropy as is the case with V7. This is the case for the sample of 80 firms surveyed in the marine industry in Australia, and another survey in a different sector might yield different results. As Georgescu-Roegen (1966, p. 78) sums it up for Boltzmann's formula[5]: "If the higher the disorder the greater is the probability of its occurring, then obviously any closed system –such as nature – has a tendency to pass from any state to one of higher disorder".

Table 9 summarizes the results of Table 8 in terms of the four PROBB and total. We can see -in this way- what the effect is of each PROBB on the V variables. Some of these effects will be discussed in the last section below. Thus, for example, the POS is the most influential entropy-wise on V11 (10 significant correlations), and so on.

Table 9 Summary of the effects of the four PROBB on individual Vs

	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**	**V11**	**V12**	**V14**	**V15**	**V21**
POS	4	3	5	13	3	4	10	3	9	2	10	6	5	8	13
POW	5	2	5	3	5	8	9	4	16	3	5	5	3	6	2
POM	1	5	5	5	2	4	7	7	2	3	4	5	1	4	3
POC	3	7	5	6	4	5	7	7	8	5	7	7	4	6	6
TOTAL	13	17	20	27	14	21	33	21	35	13	26	23	13	24	24

These entropy-related computations for the Vs can be complemented with the frequency of each PROBB variable appearing in these computations. Thus, from Table 8 we can see that variables X13 appears 9 times as being significantly correlated with the Vs, Y15 appears 8 times, and so on. In this way we can determine once more which PROBB variables contribute to lowering entropy in the firms. Table 10 shows the most entropy-decreasing and the least entropy-decreasing PROBB variables.

Table 10 The most entropy-decreasing and the least entropy-decreasing PROBB variables (in affecting the Vs individually)

Most	X13	Y15	Y44	W24	X9	X15	X19	X21	X27	Z25	Z31	W8	W25
Least	X10	X18	Z15	Z20	Z22	Z26	Z29	Z32	W15	W16	W32	Y14	Y21

Note: For the most entropy-decreasing PROBB variables the frequency of significant correlations with Vs individually vary from 6 to 9 (mostly 6). For the least entropy-decreasing PROBB variables the frequency of significant correlations with Vs individually vary from 0 to 1 (zero for first 11 out of 13 in the Table)

We will finish this section by examining two special variables in the survey, those indicating waste of time (V*16) and negative emotions (V*20). Both these factors are a primary consequence of entropy increasing in any system and indeed in a firm and both indicate waste. The latter is the most obvious consequence of law of entropy (see for example the pioneering work by Georgescu-Roegen (1966, 1971). Table 11 shows which entropy-related PROBB variables are strongly correlated with these two V*s.

Table 11 High correlations between the waste and PROBB variables

[5] In many economics applications a modern version of Boltzmann's formula is used: where S stands for entropy and f_i stands for the fraction in microstate i (see Ayres, 1994, p. 36).

V*16	X5	X25	Y33	Y39	Y40	Z2	Z17	Z27	Z38	W3	W5	W7	W14	W29	W31
corr	-0.16	-0.15	0.2	0.14	0.23	-0.15	0.14	0.22	-0.19	0.16	0.16	0.17	-0.23	-0.18	0.21
V*20	X5	X6	X10	X13	X24	X25	Y33	Y36	Z24	Z25	Z30	W2	W13	W24	W30
corr	0.24	0.23	-0.24	0.24	-0.32	0.33	-0.27	-0.21	0.23	-0.29	-0.23	0.29	0.27	0.22	-0.23

All signs of the correlation coefficients are the correct ones based on a priori considerations. For example, negative emotions (V*20) are negatively correlated with inertia (X10); this makes sense as a state of inertia (not enough actions) usually brings negative feelings, etc. These results will be further examined in the next section.

Discussion of main results and conclusion

Entropy is a well known phenomenon in physics. Social sciences have imitated its usefulness in the areas of economics, information theory, and so on, but without any substantial success. In the present study we consider entropy as a general natural tendency for waste and inefficiencies in business unless some measures are continually taken to slow down this tendency. This paper is only a modest attempt to quantify -in simple ways- the phenomenon of entropy in business. The latter takes various forms as seen in Table 1: waste, inertia, lack of information, and so on. In order to measure all these forms we used primary data of a survey of marine industry firms in Australia according to the PROBB (process of the 'black box') model. This model is represented by 109 organizational cum managerial variables shown in Table 2 of the text. The PROBB variables can *fully* describe and explain the structure and functioning of a firm. The main task was to measure the extent to which these PROBB variables affect some strategic cum performance variables (the Vs in the text). In general, when the PROBB variables are positively and strongly correlated with the Vs then we suggest that they become entropy-decreasing[6] factors (and vice-versa).

Thus, "wasting time" (V*16) in firms is positively (see Table 10) correlated (therefore reinforcing each other) with "social relationships" (Y33), "imitating other firms" (Y39)", "accumulating knowledge" (Y40), "measures to reduce work time" (Z17), "reliance on physical efforts" (Z27), "contracts with customers" (W3), "making rigorous contracts" (W5), "traditions and institutions" (W7), and "negotiations with management" (W31). On the other hand, V*16 is negatively correlated (hence time-reducing) with "use of formal objectives" (X5), "use of formal forecasts" (X25), "resolving problems as teams" (Z2), "performance according to customers" (Z38), "appreciation of governance" (W14), and "unselfish staff members" (W29). It would be worth examining each one of these relationships in more depth but this is out of the scope of this paper. Nonetheless the interested readers can still do that at their own discretion and time.

However, we must cross-check these results with the correlations between the above variables (in Table 11) and the strategic/performance variables Vs. Thus, "making rigorous contracts" (W5) is strongly and positively correlated (0.28) with "sales" (V21). Consequently, if we calculate the partial correlation between "sales' and W5 by controlling for V*16 we get 0.30, which is higher as expected than 0.28 because we took away the negative influence of V*16. Similarly for other cases we can get the net (partial) correlations but in general the differences between direct and partial correlations are not large.

For the "negative emotions" V*20 waste variable we have the following positive correlations with the PROBB ones: "use of formal objectives[7]" (X5), "use of formal policies" (X6), "initiatives with

[6] In other words these entropy-decreasing variables slow down the natural tendency for the firm to be disordered, or in every day language to be badly managed.

[7] Note that the use of formal objectives (X5) enhances negative emotions (probably due to increased pressure to meet these objectives) whereas the same use of objectives decreases wasted time (negative correlation with V*16).

far reaching consequences" (X13), , "use of formal forecasts" (X25), "feedback mechanisms" (Z24), "contracts with suppliers" (W2), "firm form" (W13), and "international standards" (W24). Thus, contracts with suppliers (W2) usually have the tendency to "give headaches". On the other hand, "negative emotions" are enhanced by the following PROBB variables: "inertia" (X10), "improvisations when deciding" (X24), "social relationships" (Y33), "self-interest oriented staff" (Y36), "non-routine operations" (Z25), "automatic cooperation" (Z30), and "performance incentives" (W30). Thus, social relationships have the tendency to diminish negative emotions.

From Table 10 we can pinpoint more precisely the PROBB variables that contribute the least (not significantly related to any of the Vs) to the entropy problem. Thus, "inertia" (X10), "ad hoc decisions" (X18), "operations research methods" (Z15), "using transportation" (Z20), "tasks involving movements" (Z22), "transfers of people and equipment" (Z26), "fatigue problems" (Z29), "layout problems" (Z32), "functions" (W15), "status" (W16), and "resolving conflict" (W32) do not assist at all in reducing entropy in a given firm. On the other hand those PROBB variables that contribute the most (significantly related to at least six of the Vs) to the entropy problem (in improving it) are: "initiatives far reaching" (X13), "thinking capacity" (Y15), "imitation by other firms" (Y44), "international standards" (W24), "defending in markets" (X9), "rational decisions" (X15), "aggressive decisions re staff" (X21), "taking risks" (X27), "non-routine valuable operations" (Z25), "teamwork satisfaction" (Z31), "supervision rules documented" (W8), and " control measures" (W25). Many of these variables, both most entropy decreasing and least entropy decreasing are also present in Table 4 of the text which shows the impact of PROBB variables on the totality of the V variables. Thus, X10, Z22, Z29, and others are the least entropy decreasing variables that affect the totality of the performance variables V. These common[8] PROBB variables in Tables 4 and 10 increase the confidence we have on the whole analysis.

Other important conclusions can be drawn from Table 9 of the text which shows the importance of each PROBB on the V variables in terms of entropy. Thus, the POS (process of strategies, see Table 2) is very important in determining -hence entropy-decreasing- V4 (13 POS variables out of a total of 27 are significantly correlated with V4). This means that the way firms decide and form strategies (POS) have a significant impact on the power firms have in dictating prices and/or quantities (V4). POS has also a significant entropy effect on V11 (adoption of technical innovations) and sales (V21). The process of wisdom (POW) is very prominent in determining product uniqueness (V9); this makes sense as firms need wisdom and knowledge to create a unique product. The other two processes (POM and POC) do not seem to influence a particular V variable more prominently.

Some general conclusions can also be drawn from the present study. First, it has become apparent that the PROBB model is consistent within itself, as all correlations examined in the context of entropy make sense. Second, although we have given more emphasis to the Vs in relation the PROBB variables, another way to determine the entropy impact on firms would have been to examine the impact of PROBB variables on themselves. This alternative is the object of another paper (where for example we could use structural equations models). Third, overall, we are confident that the present analysis has provided some evidence -in a simple way- about the impact of entropy-related variables on the performance and survival of firms.

[8] It is expected that not all PROBB variables are present in both Tables 4 and 10 because the impact of these variables are either on the totality of Vs (hence Table 4) or on each V separately (Table 9).

Appendix 1: Definition of PROBB variables as per PROBB questionnaire

POS (Process of Strategies)	**POW (Process of Wisdom)**	**POM (Process of Movements)**	**POC (Process of Contracts)**
X1: use of formal strategies	Y7: using quant/e techniques	Z1: using teamwork	W1: contracts with employee
X2: use of formal planning	Y8: experience knowledge	Z2: resolve problems as team	W2: contracts with suppliers
X3: use of formal vision	Y13: education/ training	Z15: using operations research	W3: contracts with customers
X4: use of formal mission	Y14: information/ data	Z16: rationalize work	W4: support community
X5: use of formal objectives	Y15: thinking capacity	Z17: reduce work time	W5: rigorous contracts/documents
X6: use of formal policies	Y17: marketing intelligence	Z18: link work stages	W6: rigorous accounting rules
X7: expectations reflecting markets	Y18: transmitted knowledge	Z19: production routines	W7: traditions & institutions
X8: aggression in markets	Y19: product design	Z20: using transportation	W8: supervision rules documented
X9: defending in markets	Y20: insightful staff	Z21: movements organ/on	W9: ownership rules assistance
X10: Inertia state	Y21: culture in relationships	Z22: movements tasks	W10: informal v formal rules
X11: momentum	Y22: rational thinking	Z23: logistics	W11: conventional behaviour
X12: cautious style management	Y23: attitudes/beliefs of staff	Z24: feedback mechanisms	W12: rules of communication
X13: initiatives far reaching	Y31: socio-psycho/al values	Z25: non-routine operations	W13: firm form affecting you
X14: reaction unexpected	Y32: intuition/perceptions	Z26: transfers people and equipment	W14: governance appreciation
X15: rational decisions	Y33: social relationships	Z27: physical efforts reliance	W15: functions
X16: driven outside square	Y34: imagination constructive	Z28: physical efforts monitoring	W16: status hindering
X17: decisions market share	Y35: emotional state	Z29: fatigue problems	W17: hierarchy structure
X18: ad hoc decisions extent	Y36: self-interest of staff	Z30: automatic cooperation	W22: firm structure assisting
X19: Readiness to adversity	Y38: distinct capabilities	Z31: teamwork satisfaction	W23: standard legal documents
X20: easy decisions extent	Y39: imitating other firms	Z32: layout problems	W24: international standards
X21: aggression re staff	Y40: accumulated knowledge	Z33: ergonomics	W25: control measures
X22: asses/t before decisions	Y41: leadership vision	Z34: location of activities	W26: autonomy employees
X23: interpreting surroundings	Y42: leadership motivation	Z35: harmonized activities	W27: trust your employees
X24: improvisations deciding	Y43: unique culture	Z36: implementation prod/n	W28: attitude re authority
X25: use of formal forecasts	Y44: other firms imitating you	Z37: execution as expected	W29: selfish staff members
X26: uncertainty facing	Y50: needs in markets	Z38: performance as per customs	W30: performance incentives
X27: taking risks	Y51: outdated knowledge		W31: negotiating with man/t
			W32: resolving conflict
			W33: equity if crucial
Total : 27	Total: 27	Total: 26	Total: 29

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