Computer-Modelling the Innovation-Based Theory of the Firm

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Abstract.

A computer-generated 3D quantitative fold is presented called Knowledge Valley and this virtual fold is used to model an Innovation-Based View of the evolution and development of SMEs by means of the growth of their knowledge assets. By using concrete values of employee number and annual turnover the model allows detailed and largely quantitative financial estimations of potential knowledge value in organizations to be calculated and also explains from a knowledge assets viewpoint why the management crises in growing SMEs occur. This model covers all SMEs but is thought to be especially useful to SMEs in the service industries.

Computer-mediated Markov-Chain Monte-Carlo (MCMC) modelling along this fold indicates that adding middle-management innovators to low-innovation SMEs can contribute markedly to the potential financial performance of the organization. Conversely, adding innovators to the middle management of high-innovation SMEs does not provoke an absolute increase in financial returns, but rather performance levels are reached earlier, and potential financial gains can be realized indirectly by e.g. entrepreneurial spin-outs from the parent organization. However in all cases potential financial performance was dramatically improved by laying down an innovative middle-management stratum early on in SME development (size 100 or fewer employees), rather than waiting until a size of 100+ employees was achieved then trying to add innovators later. Adding a later layer of innovative managers on top of an already-established less-innovative middle management layer was markedly less effective than having an innovative middle-management in place from an early stage.

In terms of the financial performance of organizations, the possession by individuals in management (innovators or not) of relevant networks and the ability to realize "just-in-time" knowledge from external sources appears almost as important as internal innovation. Indeed the results indicate that the differences between "innovators" and "networker" can be largely evened out if "networkers" are able to access and effectively use inspiration, insights or “just-in-time knowledge” gathered from their external networks.

Keywords
Growth and financial returns, innovators, knowledge assets, management, organization, services, SME, value of networks.

Introduction

Kotler and Trias de Bes (2003) state; '*Companies need to innovate if they are to grow and prosper*' and indeed little has changed between the early work of Holmes and Zimmer (1994, p119) who state '*an operational framework that distinguishes growth from non-growth small businesses does not exist*' and more contemporary Atherton and Hannon (2001, p277) who again remarked that there has been '*a paucity of research on how innovation can arise and spread in small companies*'. Later research (e.g. Suppiah and Sandhu, 2011) still has not filled this gap in our understanding. Let us think back to over 30 years ago when Porter (1980, p 74) stated that '*companies achieve competitive advantage through acts of innovation*' and again ten years after when (Porter 1990, p4) said that '*much innovation is mundane and incremental, depending more on an accumulation of small insights than on a single major technological breakthrough*'. The finding that the sum of many incremental innovations can have a very large impact on markets, value and technology is also supported by a plethora of other authors (e.g. Bessant, 1999; Birkinshaw and Sheehan, 2002). This implies that, especially when applied across the board to SMEs, formal invention actually plays a minor part in the process of value creation across mercantile society - although specialized high-tech start-ups may form an obvious exception to this broad generalization. Carneiro (2000, p88) also agreed that "… *knowledge development is a fruitful background where incremental innovation may be attempted* …" Thus despite being hard to pin down, the fact remains that if incremental innovations are important – perhaps even the most important type of innovation when considered in an SME/service industry context – then it could be interesting for SME management and investors to understand how and where incremental innovations arise. In a seminal work Iansiti (1993) indicated that incremental innovations arise preferentially in certain individuals and refers to individuals able to sustain meaningful and synergistic relationships with others as possessing 'T-Shaped Skills', referring to depth in a particular discipline but combined with a breadth of understanding of other disciplines. This view has been expanded upon to include 'A-Shaped Skills', multi specialists possessing dual deep (often technical) skills and an accessible overview of this subject can be found in e.g., Yang, Kang and Mason (2008). There is increasing evidence connecting multi-skilling (also variously described as T-shaped or A-shaped skills) with increased innovations as contrasted with the number and level of innovations created by people with a work single specialisation (Tsai and Huang, 2008). Mellor, (2011) speculated that the amount of communication between two individuals needed to create "mutual inspiration" or another innovative outcome is subject to transaction costs (Williamson 1995) but that in the multi-skilled, such transaction costs are negligible. Due however to environmental (externalities) and market uncertainty, statistically-valid results of optimized financial performance from rigorous long-term experiments can rarely be obtained, one clear factor being the lack of control experiments, another being the large amount of effort needed to statistically analyse case-based work for a result which is neither fine-grained nor applicable over a longer timeframe due to changes in mercantile reality (recession etc.).

Thus pure computer modelling was employed to model the development and evolution of the SME (Mellor, 2011 and Mellor, 2014a). This approach enables one variable to be changed at a time, thus incorporating the elements of control experiments and enabling the construction of a fine-grained framework which in based soundly on financial values. By attaching concrete values to growth stages, Knowledge Valley Theory may have many practical uses and be of value to business consultants, as well as academics.

This model coherently explains the growth and crises that expanding SMEs experience (see e.g. the Greiner "5 stages model" of SME evolution (Greiner, 1972)) which is particularly applicable in knowledge intensive areas like services (Mellor, 2014a). The same computer virtualization (Markov-Chain Monte-Carlo, MCMC analysis) was used to model the effect of adding innovators to the middle management of organizations (Mellor, 2014b) however the figures resulting from the analyses indicated that a rather unrealistically high proportion (50%) of such employees should be innovators, specifically that a half of the management should be innovators in order to reproducibly realize significant financial gains. One possible explanation for this high figure is that the Mellor (2014b) model only took internal networks into account and neglected the effect of external networks, the importance of which has been understood in a qualitative sense for some time (e.g. Kogut, 2000). Thus this work also uses MCMC techniques similar to before (Mellor, 2014b) to model and quantify the effects that the possession of external knowledge networks by individuals may have, on the potential performance of the firm.

Modelling.

The 3D fold "Knowledge Valley" used is shown in Figure 1 and has previously been comprehensively described in Mellor (2011) and again in Mellor (2014a). Briefly, A peer-to-peer model was constructed where people in an organization are represented as nodes (the number of people is represented by P), and are joined by ties. The number of links or ties between nodes is the Diversity Innovation (DI) number. As the DI number increases the potential for knowledge recombination into innovation increases. When two individuals enter into a communicative relationship, then a communication pathway (sometimes called a link or 'tie') opens, i.e. the DI number reaches 1. As long as the number of people involved is larger than 3, then the number of pathways is related to the number of people involved and this relationship can be expressed by a simple equation (note that an asterisk, *, is the mathematical symbol for multiply):

$$DI = \frac{P * [P-1]}{2}$$

Using this equation the amount of potential DI (i.e. the potential for the generation of new and profitable ideas) in an organization as it grows and acquires more employees can be calculated. Widespread rampant knowledge sharing and consequent recombination of diverse knowledge into useful innovation is unfortunately prevented in practice by the concomitant increase in Transaction Costs for communication, i.e. the time taken to communicate. Furthermore as an organization grows, unfettered knowledge sharing is no longer possible because at around 50 employees, Transaction Costs force SMEs into a policy of departmentalization, and the effect of forming departments is to reduce the DI number in periodic cycles in tact with each round of departmentalization. The key values on the X and Y-axes are thus number of employees (X axis) and financial performance (Y axis). The Z axis is a benchmarked scale of where an organization can be placed on a 1-100% scale, the maximum (100%) being calculated using the DI equation. The third dimension of the model is given by a J-curve, because the J-curve represents a transition where – put simply – things get worse before they get better. Nonetheless taking a traditional company as starting point and transforming it, a successful Knowledge Management project will, at maturity, approximately triple the value of an organization (noting that exact figures are not possible to e.g. the nature of accounting practices, inflation and that the world will have moved on). Higher values – reaching up to 10 – have been reported by e.g. Lillrank & Holopainen, (1998), but these are regarded in the industry as being very special cases and are much trickier to compare as they often pertain to newer companies i.e. comparing Internet-based companies with a purely theoretical non-Internet baseline. The values used in constructing the J-curve used here are given in Mellor (2011) and in Mellor (2014a). This 3D fold now allows the percent use of innovation to be plotted against financials, resulting in a J-curve that represents the expected curve of a Knowledge Management operation taking a low-innovation organization ("Dickensian") from the left, to a higher state ("Schumpeterian") on the right, the high-value organizations on the right representing those able to use Schumpeterian innovation to create more value. These are the "gazelles" of the sector. These curves are represented in the 3D fold presented in Figure 1.

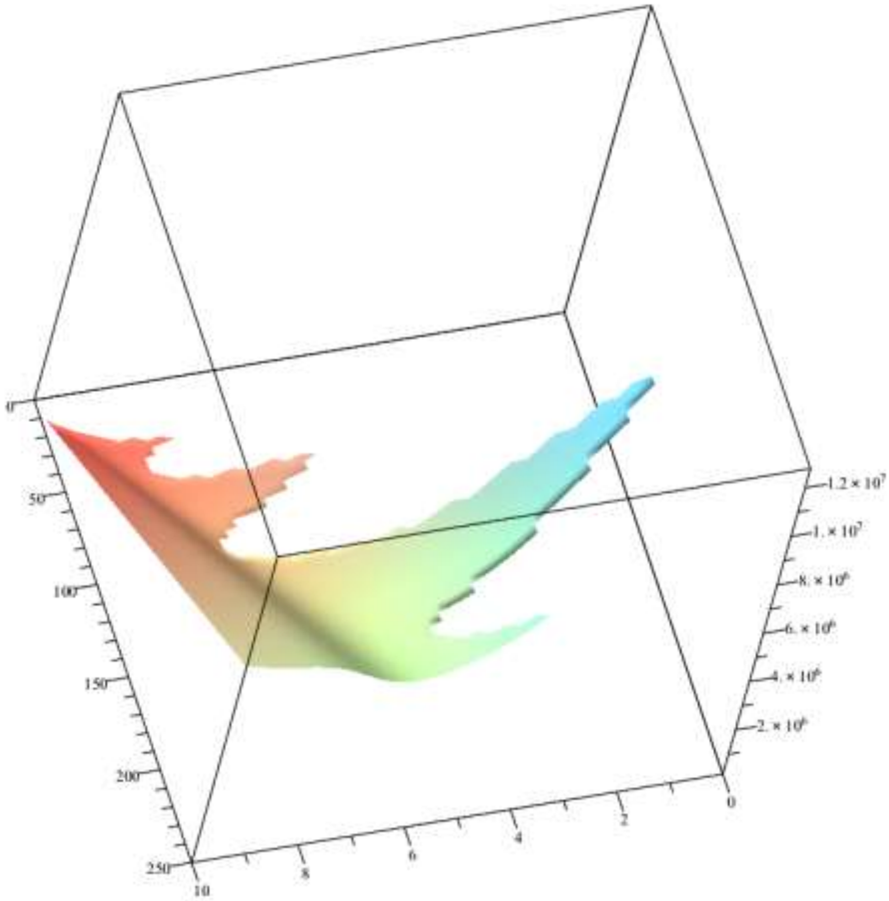

Figure 1: The 3D fold also known as Knowledge Valley (see Mellor 2011) with on the abscissa the origin at 0 employees and that x-axis extending to 250 employees. The ordinate y-axis represents annual turnover in GBP (value at 2008) and the Z-axis is benchmarked openness to innovation, with 0 (zero hindrance) being very innovative, representing the "Schumpeterian" side of "knowledge valley" and the opposite end of the scale (10) representing the "Dickensian" side.

Markov-Chain Monte-Carlo -MCMC analysis:

MCMC involves recognizing the 3D fold as shown in Figure 1 as a (pseudo)Markov Net. In Monte Carlo modelling virtual "balls" are bowled along the net, usually from the origin, and a scatter plot is made of their impact on the opposing side. For ease of viewing the scatter plots are typically represented as impact density functions (Mellor, 2014b). Figure 2 (next section) provides an example of this, derived from the results described previously in Mellor (2014b).

Analysis and Findings 1: Adding innovators to middle management.

Where the valley consists of a homogenous and uniform net, the Monte Carlo balls from the origin will arrive in a random fashion. Placing 100% innovators longitudinally along the pathways described resulted in scatter distribution apparently exhibiting the characteristics of a Probability Density Function; however the curves obtained from repeating the process several times showed this curve not to be Gaussian but rather to be platykurtic i.e. where the peak of the distribution is flattened. Table 1 shows that even with 100% innovators on a knowledge trail, the scale parameter (small sigma; σ) did not achieve unity (1.0), which it would have to do, in order to be a Gaussian distribution. Values of scale parameter, small sigma (σ) of 3 and above were discarded because values above 3 are not significantly different from an even line.

Percent innovators	Value of scale parameter (σ) to with a confidence of >90% where n = 10
100	1.12
90	1.16
80	1.20
70	1.26
60	1.38
50	1.50
40	1.78
30	2.18
20	2.99

Table 1: The effect of the number of innovators along the bifurcating pathway on the value of the scatter plot scale parameter (small sigma, σ).

Thus the number of innovators down the knowledge trail, was adjusted until scatter plots with a scale parameter (small sigma: σ) of minimum 1.5 was reproducibly achieved and where the location parameter μ=1 (i.e. the location parameter was centred on the intersection between the knowledge trail and the J-curve). This more realistic cumulative distribution function was first obtained when the ratio of overlapping nodes to non-overlapping nodes was 1:1, i.e. every second person in the knowledge trail was a multi-skilled potential innovator. This was the case (i.e. the difference in σ was not statistically significant) if the overlapping nodes were distributed randomly along the knowledge trail or if deliberately placed in every second position (Mellor, 2011).

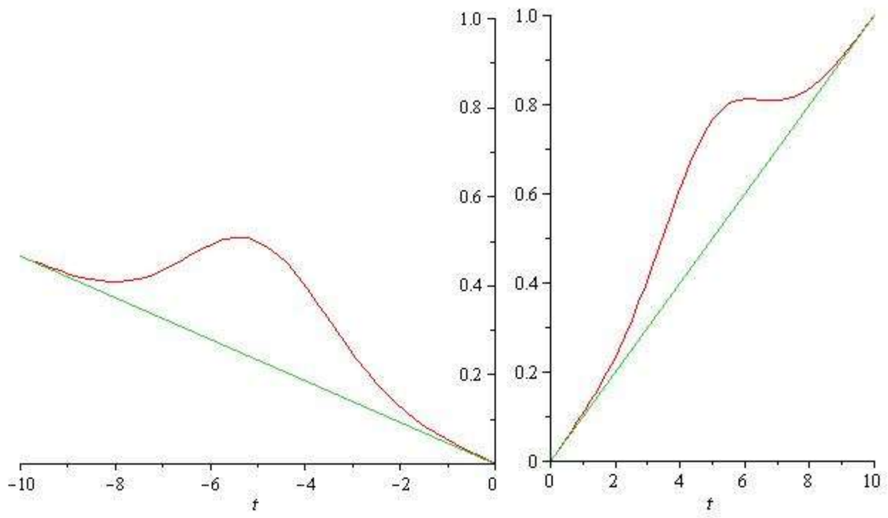

Figure 2: The impact of spontaneous knowledge trails formed by overlapping nodes in areas to the left and right of the J-curve (i.e. possible effect on innovation and hence by implication, value, of a multi-skilled middle management layer).

As figure 2 shows, companies showing a low percent of use of innovation (i.e. being on the left, Dickensian, side of the J-curve) can profitably use multi-specialized individuals in middle management and indeed things may seem to get quite a lot better (remember the vertical axis is value) as the organization opens up to innovation and change. However, as they proceed along the skewed distribution curve (moving right) they approach a decline, the nature of which could be very diverse depending on branch and industry, but in any case may be disadvantageous as value rapidly decreases.

Figure 2 also shows that companies showing a high percent of use of innovation (i.e. being on the right, the Schumpeterian, side of the J-curve) can likewise profitably use multi-specialized individuals in middle management. The model indicates that only low or no risk is associated with this strategy and, if it works, things may get much better very rapidly indeed. After this gain in value is realized, added value will reach a drained plateau and level off. But the scatter plots show that when the plateau is reached, developing more multi-skilled knowledge trails, or increasing the numbers/density of multi-skilled individuals (i.e. hiring more) on existing knowledge trails, should not have much further effect. If the effect of these innovators is not fully aligned with the core competencies of the mother organization, then value can still be extracted by intrapreneurial (spin-out) activities, should the original organization be sufficiently entrepreneurial.

Analysis and Findings 2: Temporal effects of innovators in middle management.

In order to investigate the effect of longitudinal distribution of innovators further, a more massive inequality in innovator distribution along the bifurcating pathway was investigated: Innovators were distributed along the bifurcating pathway using a Pareto distribution, firstly partitioning 80% of innovators upstream in the first half of the Knowledge Valley fold i.e. earlier in the history of the organization, in the area 0-100 employees, and secondly partitioning 80% of innovators downstream in the second half of the Knowledge Valley fold i.e. in the area 100-200 employees. A random longitudinal distribution (as before) was used as an internal reference. Table 2 shows that the effect of massive inequalities in distribution was very clear:

	80 upstream: 20 downstream	Random (control)	20 upstream: 80 downstream
Schumpeterian side	1.21	1.50	1.61
Dickensian side	1.22	1.50	1.63

Table 2: The effect of the Pareto distribution of innovators along the bifurcating pathway, on the value of the scatter plot scale parameter (σ).

Partitioning innovators into the historically early part of the fold had a dramatic effect of tightening the scatter plot and this effect was more apparent on the 'Schumpeterian' side of Knowledge Valley containing the more innovative organizations. Partitioning innovators downstream had two effects; it made the scatter plots slightly fuzzier than the control, it also appeared to make the difference between the results obtained from the two sides of the fold less dramatic.

Analysis and Findings 3: The effect of external networks in providing "just-in-time" knowledge.

In Analysis and Findings 1, all Monte Carlo balls started at the origin of the fold (Figure 1), but to mimic the random arrival of "just-in-time" knowledge from individuals outside of the organization, the same overall number of balls were rolled down a fold in an exactly similar way as before, except that a variable proportion of these balls appeared "spontaneously" in a random fashion within the innovator band. Experiments tested the proportion of balls at 33:66, 50:50 and 66:33. This is meant to simulate the number of innovations (number of balls) being constant while the number of innovators responsible for them was varied, the balls appearing at random represent inspiration coming in from outside the organization (and thus can appear anywhere along the band). The ratios represent one innovator using their network to harvest 2 innovations (33.3:66.6), one innovator bringing in one inspiration from outside (50:50) and finally the network value being one solution from outside for every 2 innovators in the organization (66.6:33.3). The resulting values of scale parameter are shown in Table 3.

Source mix	Scale Parameter (value)
1 innovator & 2 external sources	1.12
1 innovator & 1 external source	1.38
2 innovators & 1 external source	1.46
Innovators only	1.50

Table 3: The effect of changing the proportion of MC balls starting at the origin of the fold on the scale parameter of the resulting scatter plot. Please note that these results only apply to the "Schumpeterian" slope of the Knowledge Valley fold (as shown in Figure 1).

It can be seen from Table 3 that innovators capable of effectively calling in "just-in-time knowledge" dramatically tightened the scatter plot distribution, indicating that they can indeed add significant value to the organization. The "innovators only" score represents the situation where half of all individuals in middle management are innovators, often exhibiting multi-skilling ("T-shaped" or "A-shaped" skills, for further explanations see e.g. Tsai and Huang, 2008 and Mellor 2011, 2014b). This value was taken rather serendipitously and largely because the lowest value of scale parameter obtained to date was using 100% of individuals being innovators (Mellor, 2014b) and this was regarded as being so seldom in practice as to be highly unrepresentative. The value obtained for 100% innovators was 1.12 (Mellor, 2014b), from Table 1 it can be seen that this value is very similar to that obtained using individuals whose external links can provide timely solutions or inspiration. This shows that the ratio of innovators in management can be as low as 1:6 of all individuals provided that the innovators or other individuals in the same management stratum have active external networks that are able to gather relevant "just-in-time knowledge" as well as clear open internal information gatekeeping, enabling solutions, suggestions etc. to be acted upon in a prompt and effective way.

How many external network contacts an individual needs is of course a moot point; certain individuals may have 100s or thousands of contacts but the absolute number will of course be relatively meaningless if they are not relevant to the problem at hand. Action on these "mutual inspirations" must also be effective; Kirton (2003) also showed that problems with information gatekeeping will grow to significant proportions for those innovative individuals outside the "consensus group", contributing in turn to more friction and ultimately causing higher Transaction Costs, thus partly or totally negating the addition of value caused by improving knowledge assets.

Conclusions

The experimental findings presented here and elsewhere strongly imply that adding middle-management innovators to low-innovation SME environments can result in real bottom-line gains for the SME-sized organizations: The results indicate that low innovation organizations (those at the "Dickensian" side of the 3D fold) can profitably use innovative multi-specialized individuals (those with “T-shaped” or “A-shaped” skills) in middle management to increase knowledge value and modelling indicates that the company’s general financial health may improve considerably as a result of increasing knowledge assets. As the organization opens up to further innovation, the strategic choices for the leadership are in all probability either to watch and control this process carefully, or to deliberately plunge through a major BPR-type transformation with the aim of becoming a high-innovation organization. Obviously miscalculations at this point may have very unfortunate consequences, including bankruptcy, for the organization in question.

The experimental findings also imply that adding middle-management innovators to high-innovation SME environments can also lead to gains for the organization but in this case the modelling indicates that these may not be absolute gains, but rather that the organization continues to achieve the potential that Knowledge Valley says it should, but it may do so earlier or easier: However in contrast to low-innovation environments, high-innovation organizations can profitably use multi-specialized individuals in middle management even when the skills brought in, and the innovations generated, are not in close alignment with the company’s core competencies, providing that the organization involved can act in an innovative and entrepreneurial fashion by levering intrapreneurship (also known as “Corporate Entrepreneurship”, see e.g. Burns, 2008) and spinning out any initiatives that are not in alignment with the core competencies of the parent organization. Obviously miscalculations at this point may have unfortunate consequences for the organization, but the consequences of these are unlikely to be as serious as similar miscalculations made in low-innovation organizations.

The results obtained from placing innovators upstream and downstream (i.e. historically earlier or later in a developing organization) strongly imply that hiring innovative managers into an existing and expanding medium-sized organization that is already populated by a well-established class of less innovative managers can add value. The results also however imply that putting an innovative middle-management in place early in the development of an SME is significantly more likely to result in adding value for the organization. Thus adopting a policy of hiring high innovators from the very start implies the highest potential returns. However the difference can be evened out if latecomers are able to access and effectively use inspiration or ‘just-in-time knowledge’ gathered from their external networks.

The results presented pertaining to networking and the availability of “just-in-time” knowledge show that multi-skilled innovators with good networks are much more valuable than being a multi-skilled innovator alone. Indeed, it may be that a non-innovator individual with a good network is as valuable as a multi-skilled innovator lacking an effective network, and that a reasonable mix may be innovators together with well-connected non-innovators. The final mix may well depend on industry sector. The reason behind this speculation is that in an early work on comparative entrepreneurship Mellor and co-workers (Mellor et al, 2008, p15) showed that in technical areas invention and innovation are more important than networks, whereas in arts and entertainment, it is networking that is supremely important. It is assumed that SME owners will instinctively have grasped this and will steer the mix accordingly.

References

Atherton, A. and Hannon, P. D. (2001): Innovation processes and the small business, a conceptual analysis. International journal of business performance management, 2, 276-292

Bessant, J. (1999): Developing continuous improvement capability. International Journal of Innovation Management, 2, 409-429.

Birkinshaw, J. and Sheehan, T. (2002): Managing the knowledge life cycle. MIT Sloan Management Review, 75-83.

Burns, P. (2008): Corporate entrepreneurship: building an entrepreneurial organisation (second edition). Palgrave Macmillan, Basingstoke.

Carneiro, A. (2000): How does knowledge management influence innovation and competitiveness? Journal of Knowledge Management, 4, 87-98.

Greiner, L. (1972). Evolution and revolution as organisations grow. Harvard Business Review, 50, July/august, 37-46.

Holmes, S and Zimmer, I. (1994): The nature of the small firm, understanding the motivation of growth and non-growth oriented owners. Australian journal of management, 19, 97-120.

Iansiti, M. (1993): Real world Rand; jumping the product generation gap. Harvard Business Review, 71, 138-147

Kirton, M.J. (2003): Adaptation and innovation in the context of diversity and change London. Routledge.

Kogut, B. (2000): The network as knowledge: Generative rules and the emergence of structure. Strategic Management Journal, 21, 405–425.

Kotler, P. and Trias de Bes, F. (2003): Lateral marketing. John Wiley. New York.

Lillrank, P & Holopainen, S. (1998). Reengineering for business option value. Journal of Organizational Change Management, 11, 246-259.

Mellor, R. B., Coulton, G., Chick, A., Bifulco, A., Mellor, N. and Fisher, A. (2008): Entrepreneurship for everyone. London, Sage.

Mellor, R.B. (2011): Knowledge management and information systems, strategy for growing organizations. London. Palgrave Macmillan.

Mellor, R.B. (2014a): Knowledge Valley Theory. International Journal of Knowledge-Based Development, 5, 5-16.

Mellor, R.B. (2014b): The use of knowledge assets: Modelling the potential effect of adding innovators to low-innovation and high-innovation SMEs. International Journal of Knowledge-Based Development, 5, 367-380.

Porter, M.E. (1990): The Competitive Advantage of Nations. Palgrave Macmillan, Basingstoke.

Porter, M.E. (1980): Competitive Strategy. The Free Press, New York.

Suppiah, V. and Sandhu, M.S. (2011): Organisational culture's influence on tacit knowledge-sharing behaviour. Journal of Knowledge Management, 462 – 477

Tsai, M-T. and Huang, Y-C. (2008): Exploratory learning and new product performance: The moderating role of cognitive skills and environmental uncertainty. The Journal of High Technology Management Research, 19, 83-93

Williamson, O. E. (1995): The Economic Institutions of Capitalism. New York, The Free Press.

Yang, H-D, Kang, H-R and Mason, R. M. (2008): An exploratory study on meta skills in software development teams: antecedent cooperation skills and personality for shared mental models. European Journal of Information Systems, 17, 47–61.