Stimulating Manufacturing Excellence in Small and Medium Enterprises
VII SMESME CONFERENCE 12-15 JUNE 2005, GLASGOW

Predicting the outcome of New Product Development : a Techno-Economic Model applied to SME's in the manufacturing sector.

by S F Bush and C Doidge
Centre for Manufacture, University of Manchester, P O Box 88, Manchester, M60 1QD

Abstract

The purpose of this paper is to present a Techno-Economic Model (TEM) whose object is to predict the likely outcomes of projects seeking to commercialise innovative product and process ideas. A particular objective of the research is to provide managers with a quantitative methodology for deciding which ideas should be pursued and which ones abandoned, and where an idea is pursued, how resources should be apportioned: between research and design, production and sales.

The TEM is applied in the paper to two examples closely modelled on real-life experience. One is where a new product idea requires an entirely new company, and process equipment is needed to commercialise it. The other example is where an existing company launches a new product on existing plant through an existing marketing and sales network.

The results demonstrate how sensitive the financial outcomes can be to the starting investment, the split of resources between R&D and marketing, and the timing of additional investment. Cross reference is made to aggregated results obtained from 53 other SME innovative projects over the last eight years.

Keywords:

Techno-Economic Model; Innovation; New products; Small and Medium-sized Enterprises.

1. Introduction

Nationally, science-based innovative enterprise, and how to get more of it, has become one of the major public issues of the day. The Centre for Manufacture (CfM) was set up in 2000 in the University of Manchester to pursue this objective in a systematic way in the field of manufacture. At the same time NEPPCO Ltd was incorporated with around 60 shareholder companies (Bush 2000). NEPPCO Ltd grew out of the North of England Plastics Processing Consortium formed in 1990 but it now provides design and manufacturing services to the process industries more generally. Taken together, the Centre for Manufacture and NEPPCO Ltd has been a successful model for integrating the science and business of manufacture, particularly for small and medium-sized enterprises (SMEs) as reported to the Vth Intl SMESME Conference in 2002. Of the 82 projects which CfM and its predecessor organisation have undertaken with SMEs, 24, among them some of the most successful, have been with NEPPCO shareholder companies.

The number of factors influencing the success or failure of an innovative idea is very large. This paper explores these factors quantitatively in respect of two innovation types: (1) a completely new plastics product for the distribution industry, for which a new selling and marketing company has been set up from scratch, and (2) a new product range introduced by an existing company in the foods business.

2. Techno-Economic Assessment

Where a proposed research project is aimed both at generating new knowledge in its field and contributing to economic benefit, it is necessary to subject the proposal to a specific techno-economic assessment. Whilst passing a suitably techno-economic assessment of the proposed project is no guarantee of success, not doing one is virtually a guarantee to failure in economic terms and possibly technological terms as well.

Methodology

The paper (Bush 2002) given to the Vth SMESME International Conference in 2002 described the organisation of a long-term programme of innovation, and presented results from 12 individual projects in the form of the ratio of added value created to the research and design costs involved. A simplified Techno-Economic Model (TEM) for converting cash spent on research and design into added value through investment in new production and sales facilities was briefly outlined as the theoretical basis for predicting this ratio, albeit with a number of the key parameters remaining to be found.

The present paper uses data for these parameters obtained from a further 33 projects carried out under the programme, and elaborates the basic model elements in three key areas: the way research and design knowledge is embodied in products and processes; the quantification of management attitudes expressed as willingness to invest; and the actual investment in plant and sales effort needed to get new products successfully into market. Data relating to the key ratio of sales generated to research and design resources used have also been obtained from 34 SMEs completely outside the programme (Doidge 2004). Overall, data from a comprehensive range of SME manufacturing sectors have been obtained, plastics, chemicals, food, electronics, metal fabrication chief among them.

Two projects have been chosen for this paper to illustrate the concepts underpinning the new TEM. While very different in character and products, both project types (1) and (2) have been concerned with the distribution of resources between the five main functions captured by the Techno-Economic Model (TEM): research, design (and the split between process and product), investment, production; sales and marketing. Knowing the feasibility and financial boundaries for the two projects, the TEM is used to generate market share and cash flow versus time trajectories as functions for instance of R&D and marketing resources, changes in the external (exogenous) variables - particularly competition, interest rates and raw materials' costs, and decisions on borrowing to expand production capacity and sales.

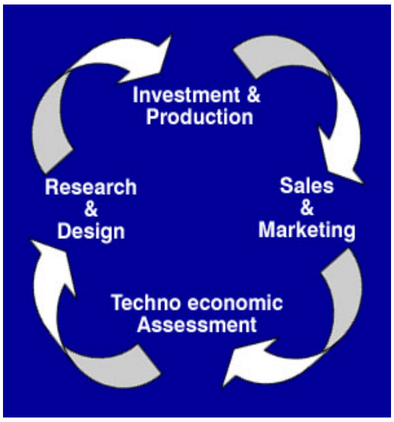
The product for the type (1) project is typically the plastics roll container described by Bush and Ademosu (2003) but stands for any large product of radical designer entering an already fully supplied market. The particular product described is a finalist in the 2005 Plastics Industry Design Award.

Product type (2) is typically a new food product to supply a market niche as described for instance in the Manchester Evening News (2001). This product also won a prize for innovation for the Centre's project scientist involved (Emma Pugh).

3. Description of the Techno-Economic Model (TEM)

Fig.1 shows the basic decision/resource sequences needed to commercialise a new product either involving the design of new manufacturing equipment and a marketing and sales organisation, or using an existing manufacturing production line and sales network, modified for the new product.

Fig.1 : Basic Sequences Needed to Realise a New Product.



(Bush 2005)

The cyclic form of the sequences in Fig.1 emphasises two points often lost in public discussion of innovation and enterprise: research and design is only one of several elements in the creation of a new product or process; and new ideas can enter at any point of the cycle which may be traversed several times during their gestation. To be useful, the basic structure of Fig.1 must be made quantitative to the point where the management of a company can take decisions to launch a project, to continue with it, or as important, to stop it. In particular, provision must be made to provide the necessary investment in production and marketing facilities so that sales can reach a self-sustaining level within a set time-scale. Matching resources to the research and design to achieve this is what is meant by the "stoichiometric" principle of innovation. This is one purpose of the TEM as applied to an individual company in competition with other companies. The results section gives output from the model showing how easy it is to breach the stoichiometric principle particularly when under heavy competitive pressure.

TEM As Sub-Model In wider Techno-Economic Model

The TEM sits within the broader model of the national economy, referred to as the Economic Engineering Model EEM, which has been developed over a number of years (Bush 1999). The EEM is constructed as a system of cells connected by flows of goods G_{ij} and cash F_{ij} flowing from cell 'i' to cell 'j'. Fig.2 shows the principal cash flows within the national economy and between it and abroad. Even for a model of a single company, the framework in Fig.2 is important because a company's ability and willingness to invest in R&D and the much larger sums needed to translate the results into actual income-yielding products depend in a major way on competition for sales including that coming from abroad [sector (5)], on interest rates set by the financial sector (2), and on tax rates set by the Government sector (3).

However, in order to examine specific company behaviour in a particular field, as in this paper, competition may be lumped as coming from a single sector denoted zero. While there is no theoretical restriction on the sectors which can be included, the companies which CfM has worked with sit within one of five manufacturing subsectors – chemicals, plastics, engineering, food, and electrical products.

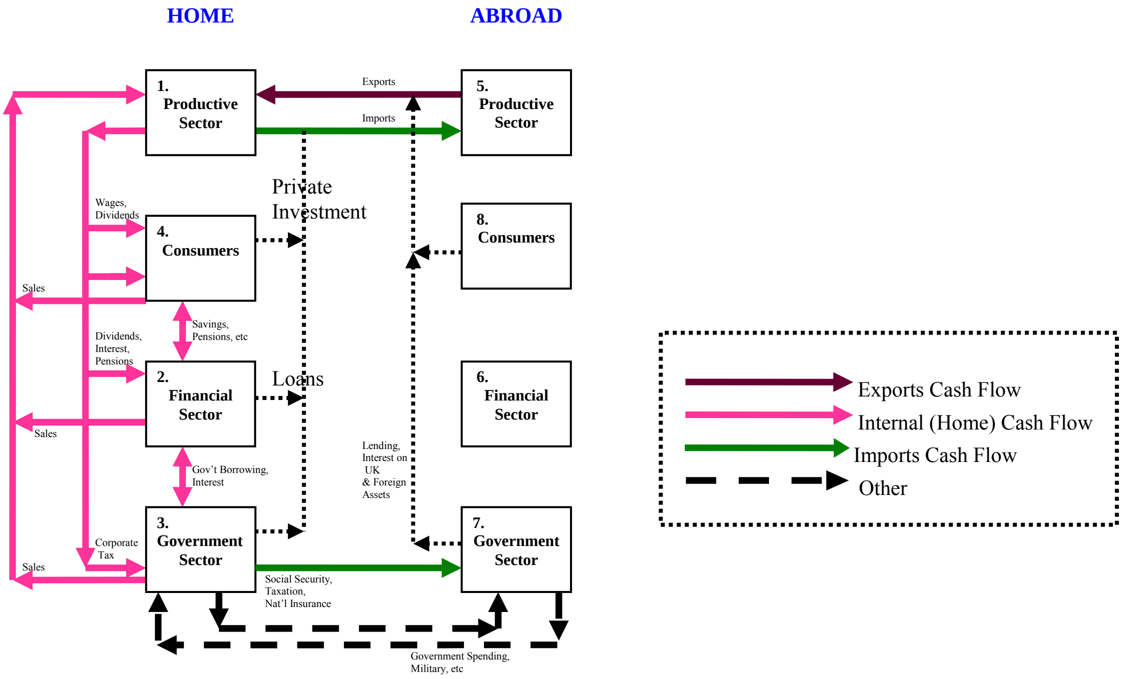


Fig.2 : Principal Cash Flows in the Macro-Economy (Bush 1999)

Reducing the number of variables for TEA purposes

The individual company making specific products, is at the heart of the EEM productive sector and Fig.2 shows how it is linked to the wider macro-economy. For the techno-economic assessment of innovative projects in particular companies, the number of variables in the techno-economic model of a company may be reduced by treating three variables linking the production sector (1) to the other sectors (2), (3), (4), namely interest rates, tax rates, and total consumer demand F_4 as specified data. Clearly a prudent management will be alert to potential changes in any of these, but for the purpose of judging whether to invest in an innovative project, this can be done by running the company TEM for a variety of possible values of these three variables. When this is done, it is easily seen why many technically successful projects do not proceed – because the financial outcomes are unfavourable. Each of the four functions in Fig.1 will now be taken in turn starting with research and design.

Research and Design Submodel [Appendix Eqs (1) – (3)]

The key relationships are those which translate a given expenditure on R&D knowledge into new plant and products as shown in Fig.3 (Kristiansen 1999).

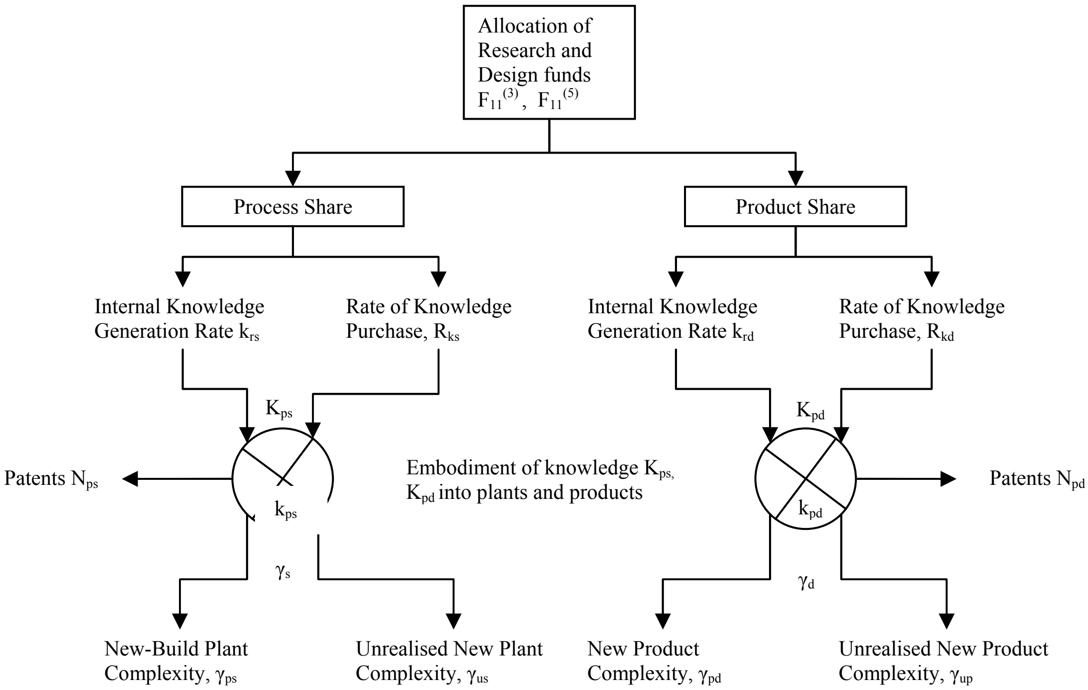


Fig.3 : Research and Design Submodel (Kristiansen 1999)

Research expenditure is denoted by $F_{11}^{(3)}$ and design expenditure by $F_{11}^{(5)}$. Both are split between product and process. This reflects the fact that different industries and different companies even within the same industrial sector often attach different priorities to these two areas. At one extreme, the production of bulk chemicals of defined purity levels will absorb practically all of $F_{11}^{(3)}$ on new process knowledge K_{ps}, while at the other extreme, consumer-oriented goods such as food may focus most of $F_{11}^{(3)}$ on new product knowledge K_{pd}. In many companies, perhaps most, there is a tendency to favour research expenditure on new products at the expense of the processes for making them efficiently. The effect of varying the fractions (ı – ζ), ζ spent on product and process respectively is explored below. Generally it is found that the proportions ζ spent on the process in practice are theoretically too small to take full advantage of new product designs.

Equations (1) and (2) in the Appendix give the changes in year n of research knowledge $\Delta K_{pd}^{(n)}$, $\Delta K_{ps}^{(n)}$ and of design knowledge (sophistication) $\Delta \gamma_{pd}^{(n)}$, $\Delta \gamma_{ps}^{(n)}$, suffices pd, ps standing for product and process respectively. Eq (3) gives changes $\Delta \eta_l^{(i)(n)}$ in the three important efficiencies: materials, conversion and capital.

Investment and Production Submodel (Fig.1) [Appendix Eqs (4) – (6)]

Funds available for investment ($F_{ii}^{(7)(n)}$) in year n depend on the financial results of the previous year (n – 1) and on the management's attitude to risk. These attitudes are expressed quantitatively through three parameters g_1, g_2, g_3: target fraction of new capital each year; the maximum proportion of total capital represented by debt (the gearing limit); the working capital limit (fraction of annual sales as stock or work-in-progress) respectively. Broadly a bold, confident management will have high g_1, g_2 and low g_3; a cautious management the reverse, with most somewhere in between. Section 4 shows the effects of changes in g_2 across the range 0.1 to 0.9 in particular cases.

The new capacity built each year depends on $F_{ii}^{(7)(n)}$. The complexity $\gamma_{ps}^{(n)}$ of new plant equipment has a maximum value of $\gamma_s^{(n)}$ [see above eq.(2)]. But the plant or equipment complexity depends ultimately on the job it has to do – to produce new product of complexity $\gamma_{pd}^{(n-1)}$. (Only products designed before time period n will be made by plant built or acquired in year n.)

Equations (4) to (6) in the Appendix give the contemporary cost of a new piece of equipment or plant, the number $\Delta N_1^{(n)}$ of new plants built in year n, and the total available capacity $Q_1^{(n)}$ at the end of the year, in the light of any scrapped during the year.

Sales and Marketing Submodel : the Benefit Functions [Appendix Eqs (7) – (11)]

Sales in the market (cell 4 in Fig.5) are dependent on three factors: the product benefit B_{14} which is a function of sophistication γ, the market coverage f_{14}, and the price p_{14}, and the corresponding values set by the competition. There are a number of algorithms that can be used to derive the market share S_{14}, and thus sales income, obtained by a company 1 in market 4. Eq. (7) in the Appendix gives one such algorithm (Bush 1999) which captures many of the important features where N products are competing in the same market. Both Benefit $B_{14}^{(n)}$ per unit and price per unit $p_{14}^{(n)}$ may themselves be functions of the quantity of goods $G_{14}^{(n)}$ sold in year n and preceding years. Thus a consumer's appetite for more of a good decreases with the amount already in their possession. Likewise, the sale price will in general decrease with increase of the $G_{14}^{(n)}$. While the TEM has Benefit functions which express dependence on $G_{14}^{(n)}$ (Kristiansen 1999) for present purposes we will assume:

- Benefits are given by $B_{14}(\gamma_{pd})$ where γ_{pd} is the sophistication designed to perform the functions of the product, i.e. independent of $G_{14}^{(n)}$.
- The price of p_{14} of our company's (new) product is set by the management to maximise its operating profit $F_{11}^{(n)}$ in year n in the presence of competition [eq (7)] except in the early start-up years when the price is fixed by the management. This automatically reflects the effect of $G_{14}^{(n)}$ on cost of production.

Techno-Economic Assessment (TEA) and Management Submodel [Appendix Eqs (12) – (18)]

- This function closes the loop in Fig.1 so that the missing cash flows $F_{11}^{(3)(n)}$ and $F_{11}^{(s)(n)}$ for research and design, $F_{11}^{(7)(u)}$ for investment in plant, and $F_{11}^{(9)(n)}$ for marketing (determining the market coverage factor f_{14}) can be set. Also provision must be for all other costs $F_{11}^{(10(n)}$ of the business which will change incrementally as new products are introduced. There are a wide range of financial entities which need to be derived to complete a profit and loss statement for instance, and these the TEM derives Fig.4 (end of paper). For the present purposes of techno-economic assessment we need the following quantities in each year:
    - Added Value eq (12)
    - Cost of Sales eq (14)
    - Operating Profit eq (18)

The financial parameters g_i and the resource allocation parameter $\alpha^{(i)}$ are set according to the managements' characteristics (cautious, prudent, bold). The next section shows the effects of high and low values of $\alpha^{(9)}$ and g_2 in our two projects.

4. Results as Functions of a Selected Set of Management Parameters

The parameters which allow us to distinguish particular classes of product, companies, and markets may be may be seen in distinct groups. E.g.:

- Market (growth, competitor pricing)
- Production (materials and services costs, wage rates)
- External Financial (interest rates on loans and deposits, tax rates)

These are largely outside a company's control. Additionally we have process or industry specific parameters including:

- Plant features (scrap rates ks, basic unit sizes Q_u)
- Research and Design efficiencies (k_r, k_{pd}, k_{ps})

which the company can influence to a degree.

Finally, we have company specific control parameters which have profound effects on the success or failure of the innovation.

There are also initial conditions. These include inherited research knowledge K, inherited process and product knowledge (sophistication) γ, initial market coverage achieved ($f_{14}^{(0)}$), start-up production capacity $Q_1^{(0)}$, and start up production efficiencies ($\eta^{(i)(0)}$). The model is based on the start-up condition of an inherited loan charge $C_L^{(0)}$ which covers the costs of providing production equipment to make a product with initial sophistication ($\gamma^{(1)}$) entering the market 4 in year 1 at a desired production rate $G_{14}^{(1)}$.

The following figures show some of the key predicted outcomes for changes in three of the most sensitive management controls namely:

$\alpha^{(9)}$ - allocation of resource to marketing and sales as a proportion of added value $F_{11}^{(0)}$
g_2 - maximum permitted borrowing in a year as a proportion of capital value
ζ - proportion of research resources $F_{11}^{(3)}$ devoted to process change or improvement as distinct from product change $(1 - \zeta)$

Fig.4 shows changes in market share S_{14}, and net cash generated $F_{11}^{(6)}$ (after paying interest on outstanding loan, profits tax and dividends) for a typical large entirely new plastics product.

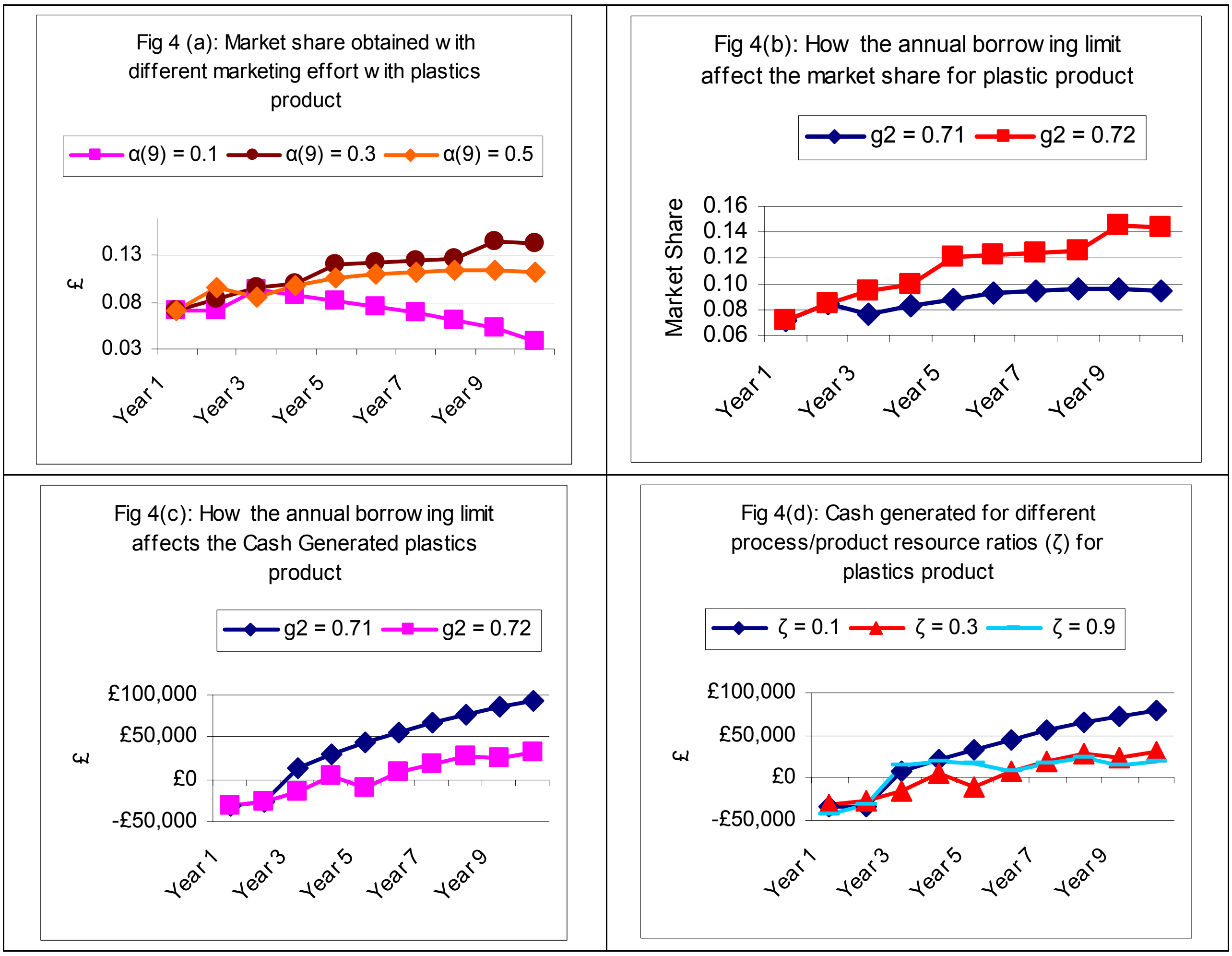


Fig.4 : Changes of Market Share and Cash generated for an entirely new plastics product and process.

The 12 cases shown in Fig.4 are indicative only of the sensitivity of outcomes to the management controls $\alpha^{(9)}$, ζ and g_2. All the cases represent changes with these controls, all other 57 parameters and initial conditions in the TEM being unchanged for these runs. These 57 have been independently checked for reasonableness, though clearly we are very interested in the effects of changes in many of them, particularly initial conditions, such as inherited knowledge.

In Fig.4(a) the market share optimising value of $\alpha^{(9)}$ arises because the product has found a value limit in its market – further marketing expenditure deflects resources from investment. The sharp effect of changes of g_2 around 0.71 [Fig.4(b) and (c)] is a reflection of drawing down more cash than can be used effectively – because of product benefit limitations – a common mistake in practice.

Fig.5 shows the same outcome variables with the same management controls ($\alpha^{(9)}$, ζ, g_2) for the new food product, starting with an existing marketing network (though requiring some spending for the new product) and paying interest on the use of an existing production line at a rate equal to its historic book value, i.e. making an appropriate contribution to payment of the company's debt.

Fig.5 : Changes of Market Share and Cash generated for a new food product on an existing process.

Fig.5(a) shows progressive loss of market share for a value of the process/product split (ζ) of 50 : 50. This decline which reflects competition (and which would have been more pronounced with no new product) is arrested in Fig.5(b) by a diversion of resources towards process improvement – specifically showing up as increased materials and services efficiencies and therefore lower prices to the customer. Fig.5(c), by contrast with the new plastics product and process, shows there is little sensitivity of net cash generated $F_{11}^{(6)}$ because with a plant already in existence, virtually no additional investment is needed. In Fig.5(d) the lowest marketing resource allocation gives the highest cash flow, because above a certain low level very little is needed for an existing marketing network – as one might judge in practice.

5. Conclusions

Principal Findings

The principal finding is that the TEM (shown in flowsheet form in Fig.6) can now get quite close to the actual experience of innovation in a range of projects besides the two described in the paper. Three things stand out. One is what may be termed the stoichiometric principle: financial performance is quite sensitive to the proportions of total resources devoted to new product research, to design, to process efficiency, to investment in manufacturing plant and equipment, and to investment in sales and marketing.

The second outstanding finding is that the difference between success and failure is critically dependent on the financial management of the company (for an entirely new product) or project (for a new product introduced within an existing product range). In particular the resources devoted to sales and marketing in the early years are critical for eventual success. The third principal finding is that unless the product is improved and refreshed by new investment it will lose market share against a continuously improving competition. The model shows moreover that in the middle years (5–7) the investment required to embody improvements is unlikely to be generated by cash flow alone so that further recourse to loan funds will be necessary, the timing of which is critical.

Research Implications/Limitations

Research into design methodology and into the development of the Techno-Economic Model is an on-going process dating back 10 years. It is probable that most of the key concepts have now been defined and put into algebraic equations. Data for these model equations have been obtained for a number of technologies in the process field but much more needs to be obtained from case studies to extend the range of applicability. However, typical figures for the cost of research and/or design knowledge are now known for these technologies so that by comparing actual costs in other cases with the lowest figures obtained, the *efficiencies* of the research and design processes themselves can be increasingly evaluated. Further work is also needed to disaggregate the benefit and sophistication functions somewhat in order to widen further the TEM's applicability.

Practical Implications and Value of Paper

How to get more innovation in Western economies is now a matter of urgency for most manufacturing companies and related government agencies alike. SMEs are seen as playing an increasing role in innovation. While the large corporate companies usually dispose of all the resources needed for innovation, if they choose to use them, SMEs generally do not. Their finance providers: banks, Venture capitalists, business angels and the like rarely have much technical and marketing knowledge. The TEM and its associated design management project aim to provide the essential framework for quantitatively linking technology and finance so that reliable quantitative predictions of failure or likely success can be made. In particular, the TEM is already proving of value in highlighting those potential innovations which will not succeed and, also, in indicating the levels of on-going research and design effort needed to sustain initially successful innovations into the medium and long terms. Within these general outcomes, we are now in a position in principle, and to an increasing extent in practice, to estimate the costs of research and design needed to reach a particular objective. This has implications also for publicly-funded research in the universities and medical institutes.

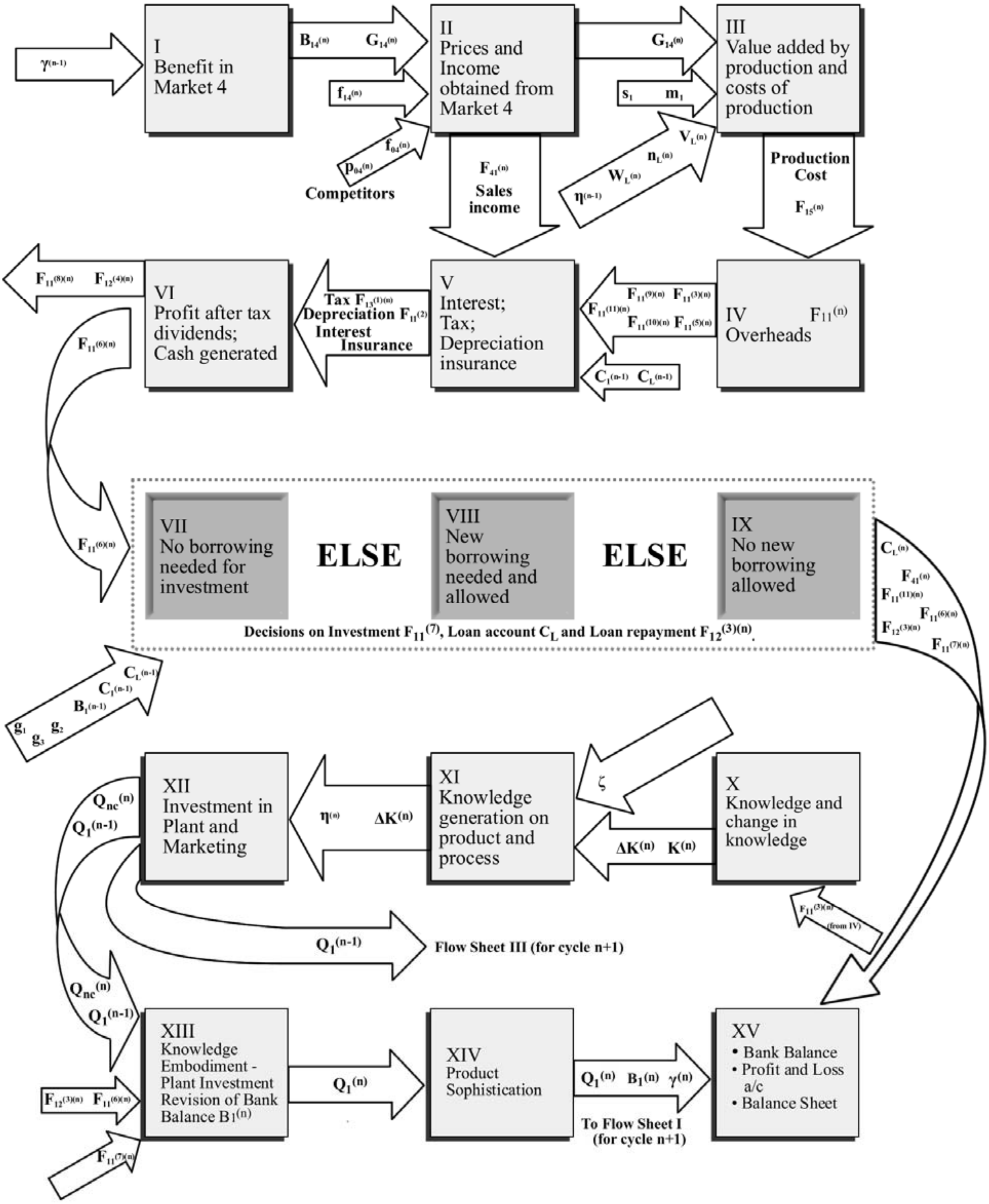


Fig.6 : Flowsheet of the Techno-Economic Model (TEM)

APPENDIX

Summary of Main Techno-Economic Model Equations

Following Bush (1999, 2005) the four principal submodels are given as follows:-

Research and Design Submodel (Figs 1,3)
Net accumulation of product knowledge:

$$\Delta K_{pd}^{(n)} = K_{pd}^{(n)} - K_{pd}^{(n-1)} = k_{rd}^{(n)} F_{11}^{(3)(n)} (\iota - \zeta)\Delta t \ - \ k_{sd} \ K_{pd}^{(n-1)} \Delta t \qquad (1)$$

and similarly for process knowledge $\Delta K_{ps}^{(n)}$ with ζ replacing (ι – ζ), and k_{rs}, k_{ss} replacing k_{rd} and k_{sd}.

The rate constants k_{sd}, k_{ss} represent rates of obsolescence typically 0.05 to 0.1 yr. The rate constants k_{rd}, k_{rs} represent the rate of conversion of cash into knowledge with units of equivalent English words (EW) (or bytes at a given conversion rate) per pound sterling (or other currency). Typically (for industrially oriented research) we find k_{rd}, k_{rs} in the range of 1 to 2 (EW/£).

The conversion of research knowledge K_{pd} and K_{ps} into design knowledge γ_d and γ_s is given by:

$$\Delta \gamma_d^{(n)} = k_{pd} \quad \Delta K_{pd}^{(n)} \qquad (2)$$

and similarly for $\Delta \gamma_s^{(n)}$.
However, the extent to which design knowledge is actually incorporated into new or improved product as embodied complexity $\Delta \gamma_{pd}^{(n)}$ and into new or improved plant as $\Delta \gamma_{ps}^{(n)}$ is dependent on the availability of investment funds $F_{11}^{(7)(n)}$ which depends on decisions made in the Techno-economic assessment function in Fig.1.

Process knowledge K_{ps} is used not only for new-build but also to improve the efficiency of existing plant. There are a number of relevant efficiencies (η) used in practice, the principal ones being $\eta^{(1)}$ [plant availability], $\eta^{(2)}$ [labour usage], $\eta^{(3)}$ [materials and utilities]. The equations for a company or plant (as cell1) are then

$$\Delta \eta_l^{(i)(n)} = \eta_l^{(i)(n)} - \eta_l^{(i)(n-1)} = k^{(i)} \Delta K_{ps}^{(n)} \ (1 - \eta_l^{(i)(n)}) \ \Delta t \qquad (3)$$

In the model the subscript 1 may be used to identify plant commissioned in different years recognising that the new builds will (in general) have the lowest efficiencies.

Investment and Production Submodel (Fig.1)

The cost $(C_u^{(n)})$ of a new plant or equipment unit is given by

$$C_{u1}^{(n)} = A_1 \left[Q_{u1}^{(n)} / \eta^{(1)(0)} \right]^{a_1} \quad \left[\gamma_{ps}^{(n-1)} \right]^{b_1} \qquad (4)$$

where A_1 is a constant characteristic of production technology in the field. The scale factors a_1, b_1 are usually less than unity, with default values of ⅔ and ½ respectively. The number of new production units acquired is then

$$\Delta N_1^{(n)} = \text{ integer} \leq \left[F_{11}^{(7)(n)} / C_{u1}^{(n)} \right] \qquad (5)$$

Total capacity at year end is

$$Q_1^{(n)} = Q_1^{(n-1)} + Q_{u1}^{(n)} \Delta N_1^{n} - k_s Q_1^{(n-1)} \qquad (6)$$

where k_s is plant scrap rate (yr^{-1}).

Note that $Q_1^{(n)}$ is ***capacity***. Actual production for sale is $G_{14}^{(n)}$ which is determined by sales and marketing up to the limit $Q_1^{(n)}$.

Sales and Marketing Submodel (Fig.1, Fig.2)

As described in the main text eq (7) defines market share $S_{14}^{(n)}$ as a function of $B_{14}^{(n)}$ and price $P_{14}^{(n)}$ of N competitors. F_4 is total demand in the consumers section of the economy (Fig.2) in the market served by these products.

$$\frac{G_{14}^{(n)} p_{14}^{(n)}}{F_4} = S_{14}^{(n)} = \frac{f_{14}\ B_{14}^{(n)} / p_{14}}{\sum_{i=1}^{N} f_{i4}^{(n)}\ B_{i4}^{(n)} / p_{i4}^{(n)}} \qquad (7)$$

Then, subject to the price being greater than breakeven ($F_{11}^{(n)}$ > 0), we find that:

$$G_{14} = Q_1 \qquad (8)$$

(i.e. operate at capacity)

and

$$p_{14} = \frac{1}{2} p_{04} R \ \left(1 + 4 F_4 / R\, Q_1\, p_{04}\right)^{1/2} -1 \qquad (9)$$

- Subscript $_0$ denotes the average of all other competitors 2 ……N in the market share function [eq (7)]
- $$R = f_{14}\ B_{14} / f_{04}\ B_{04} \qquad (10)$$
  i.e. the ratio of your market coverage x benefit to that of your competitors.
- $$B_{14}^{(n)} = B_{14}^{0} \left(\gamma_{pd}^{(n)} / \gamma_{pd}^{(0)}\right)^{b2} \qquad (11)$$
  where $\gamma_{pd}^{(0)}$ is a reference complexity in the starting year, and the index b_2 is less than unity, typically in the region of ½ to ⅔. The units of the B_{i4} will usually be the cash cost of the alternatives needed to provide ***all*** the new product's functions represented by $\gamma_{pd}^{(n)}$

Techno-Economic Assessment (TEA) and Management Submodel [Eqs (12) –(18)]

- The model operates under a policy that the permitted maximum annual investment in equipment is $g_1C_1^{(n)}$ and the permitted maximum borrowing is $g_2\ C_1^{(n)}$ in any year n.
- Added Value
  $$= F_{11}^{(0)(n)} = G_{14}^{(n)} (p_{14}^{(n)} - u_{14}^{(n)}) \qquad (12)$$
  where u_{14} is unit marginal cost
  $$u_{14}^{n} = (m_1^{(n)} + s_1^{(n)}) / \eta^{(3)(n-1)} \qquad (13)$$
  and $m_1^{(n)}$ and $s_1^{(n)}$ are materials and utilities costs at 100% efficiency (external data).
- Cost of sales
  $$F_{11}^{(11)(n)} = G_{14}^{(n)}\ u_{14}^{(n)} + L_1^{(n)} \qquad (14)$$
  where L_1 is annual labour cost associated with production.

- R & D provision

$$F_{11}^{(3)(n)} = \alpha^{(3)(n)} F_{11}^{(0)(n-1)} \quad (15)$$

- Marketing and sales provision

$$F_{11}^{(9)(n)} = \alpha^{(9)(n)} F_{11}^{(0)(n-1)} \quad (16)$$

- Management Administration

$$F_{11}^{(10)(n)} = \alpha^{(10)(n)} F_{11}^{(0)(n-1)} \quad (17)$$

- Operating Profit

$$F_{11}^{(n)} = F_{11}^{(0)(n)} - L^{(n)} - F_{11}^{(3)(n)} - F_{11}^{(9)(n)} - F_{11}^{(10)(n)} \quad (18)$$

As with the g_i parameters, the coefficients $\alpha^{(i)}$ are set according to management's characteristics (cautious, prudent, bold). As seen in eqs (15)–(17) the actual provisions for R&D, sales and management in year n depend on the added value $F_{11}^{(0)(n-1)}$ generated in the previous year.

Reference List

Bush, S F : *The Importance of Manufacture to the Economy.* 1999. Trans Manchester Statistical Society 1999-2000: 1-46.

Bush, S F : *The University as the Research Arm of Small Companies : the NEPPCO Enterprise.* 2002. Vth SMESME Intl.Conf. 13-15 May 2002. Ashcroft Intl Mgt College, Danbury, Essex UK.

Bush, S.F. and Ademosu O.K. : *Combined Foaming and Rotomoulding: The Rotofoam© Process.* 19th Ann Mtg Polym Proc Soc, Melbourne, Australia. 7-10 July 2003. 324-333.

Bush, S.F. : *A Techno-Economic Model Applied to the Development of New Products and Improved Processes. 2005 Chemical Engineering Research and Design 83 (A8) 1-9.*

Cohen, W & Klepper, S : *Firm Size and the Nature of Innovation within Industries: the Case of Process and Product R&D*. 1996a. Review of Economics and Statistics 78, 232-344.

Cohen, W & Klepper, S : *A Reprise of Size and R&D*. 1996b. The Economic Journal 106, 925-952.

Davidson, G G : *The Competitiveness of UK Manufacturing and the Role of Innovation.* 2004. M.Phil Thesis University of Manchester Inst Science & Technology.

Doidge, C : *Impact of Design and Management on the Profitability of Small Companies.* 2004. Manchester University Centre for Manufacture report UCM/2004/19.

Harris, M : *Investigating the Innovatory Role of Small and Medium-sized Enterprises.* 2001. Manchester University Centre for Manufacture report UCM/2001/4.

Kristiansen J : *Research and Technology in Manufacturing Industry : the Economic Engineering Model.* 1999. Manchester University Centre for Manufacture report UCM/1999/02.

Manchester Evening News : Innovation report Nov 27 2001.