Research and Development Resourcing When Faced with Fundamental Market Dynamics

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Abstract

System dynamics has been used over a number of years to explore and explain the role R&D can play in shaping the dynamics of a firm or industry. This article describes how a dynamic simulation model can be built which broadly characterises and captures the causal feedback structure and performance behaviour inherent to a generic R&D system within a firm. Alternative futures are played out to explore the long-term consequences of a confluence of R&D resource decisions, coupled with changes to market demand.

Keywords: system dynamics; R&D, research and development; resource allocation; R&D intensity

Introduction to System Dynamics Modelling of Research and Development Systems

Research and development (R&D) has been cited as critical to the survival and growth of technology based firms. Faced with increased competition emanating from globalisation, the viability of many established firms is based on the efficacy of their R&D activities. In some sectors R&D has continued to be intensified, in others the intensity has remain fixed, and in yet others the increase in R&D expenditure has been outstripped by an increase in sales (DTI, 2003). However, the R&D systems of many firms are like other parts of a business model, characterised by complex structure and dynamic behaviour. It is often difficult to predict or trace out the emergent consequences of sets of decisions due to the presence of delays, non-linearities and multiple causal feedbacks inherent in such managed systems. Often well intended decisions can lead to the counter-intuitive behaviour, and the manifestation of unintended and undesirable outcomes.

System dynamics modelling can help the R&D policy-decision-maker to develop structural representations of parts of the R&D system, and explore changes to internal policy and external drivers from the safety of a computer-based simulation model. Roberts (1964) developed a model of a full dynamic system underlying project lifecycles, identifying key issues relating to R&D success within the characteristics of product, firm, customer and process. An edited collection (Roberts, 1978) included not only models of R&D project dynamics but also of the connected pan-organisation and resource allocation issues. Therein Weil *et. al.* (1978) considered the example of "work-flow bunching" in which several factors (including *e.g.* human resource allocation, sequential dependencies of and feedback between projects) led to poorly distributed, oscillating workload within the R&D organisation. More recently, Roy and Mohapatra (1994) have used empirical findings to develop a model investigating the effect of workplace climate within R&D organisations, Kameoka and Takayanagi (1997; 1999) have suggested that a company's R&D intensity should be proportional to the sum of revenue growth and a technology obsolescence rate and Hansen *et al.* (1999) have discussed conserving flow rates along a linear development pipeline. Pardue *et. al.* (1999) have modelled the relationship between R&D intensity and technology diffusion in IT producing industries. They have examined the impact of short-term dynamic transients on longer term technology trajectories. More specifically Repenning (2000; 2001) has identified the issue of product development systems becoming trapped in a condition of poor performance due to resources not being appropriately applied to early stage developments but instead to later stage projects. Milling and Maier (see Milling 1996; 2002; Milling and Maier 1993; Maier 1998) have used system dynamic models to explore the relationships between R&D activity, pricing strategy & product diffusion. They demonstrate how new product development forces competitive responses in the market.

This article describes how a dynamic simulation model can be built which broadly characterises and captures the causal feedback structure and performance behaviour inherent to a generic R&D system within a firm. At present the model is populated with synthetic, but not unreasonable data. A range of different R&D policy scenarios are played out over a twenty year simulated timeframe. These alternative futures are diagnosed and compared so as to explain why some managed interventions are more successful than others. The model is used as a tool to diagnose and predict the long-term consequences of a confluence of R&D policy, coupled with changes to market demand.

In recent years, electronics firms, in particular have been faced with rising market demand along with falling sales margins (Harvey, 2004). Many have chosen to focus on reducing their operating costs by re-locating their operations to lower cost manufacturing bases. Can revenues be maintained and even improved under such market conditions through a more optimal R&D function, or is it necessary to continue to drive down manufacturing costs as a priority? In this article a number of scenarios are explored where different R&D intensities and allocations of resource are examined and reported upon. The implications for strategic direction are also considered.

The Basic Research and Development Pipeline

Figure 1 contains a diagram representing the flow of R&D projects along a pipeline. The manager has on the face of it a simple decision on how to allocate resources between research (conceptualising) and development (getting the work done). Some of the research fails and some becomes obsolescent, thus never progressing to development. A proportion of successful development is subsequently commercialised. In some firms this decision may be governed by options thinking *e.g.* waiting for market uncertainty to be resolved; additionally there may be inflows from acquisitions at various points along the pipeline. However, in this study such additional structure is omitted so as to maintain focus on the core issues. Whilst this diagram below is a useful representation of the project pipeline, it fails to capture the integrated feedbacks apparent in R&D systems that facilitate and/or impede the flow of work. In particular, the re-investment of revenues back into R&D activity is not indicated.

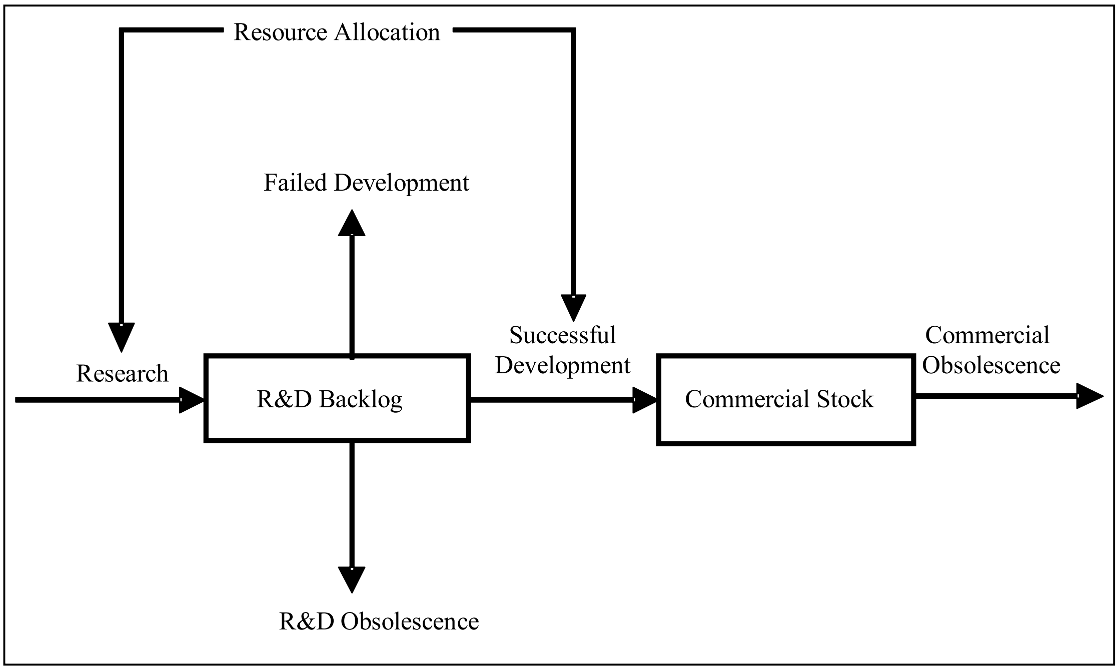

Figure 1: The R&D Pipeline

Research and Development Information Feedback

The integrated portrayal of systems structure may not be wholly familiar to many writers and practitioners. Across a firm, a number of separate models are often employed that provide detailed treatment of each domain of business activity but there is often a failure to close the feedback loops linking these functions. A typical R&D manager may work within the boundary set in the pipeline model above, without paying sufficient attention to sales and marketing, personnel, finance and information management issues.

A feedback structure of R&D that may approximate several industries is illustrated in Figure 2. The diagram contains four major causal feedback loops that link a number of R&D management activities together. A number of important stocks (accumulations) are captured within this causal feedback structure: R&D Backlog, Commercial Stock (technology stock), R&D Team and Cash.

R&D Budget is governed by both the revenues generated and the Fraction of Revenue Spent on R&D (a.k.a. R&D Intensity – ratio of R&D expenditures to revenues). If R&D Budget were lowered over time, for example, the R&D staffing would also be lowered (either through natural wastage and/or redundancies and redeployment of staff); less research would be carried out; likewise there would be a depleted flow of development; and consequently less technologies to commercialise; leading to diminished revenues available for R&D investment. Reinforcing behaviour is evident in this feedback loop.

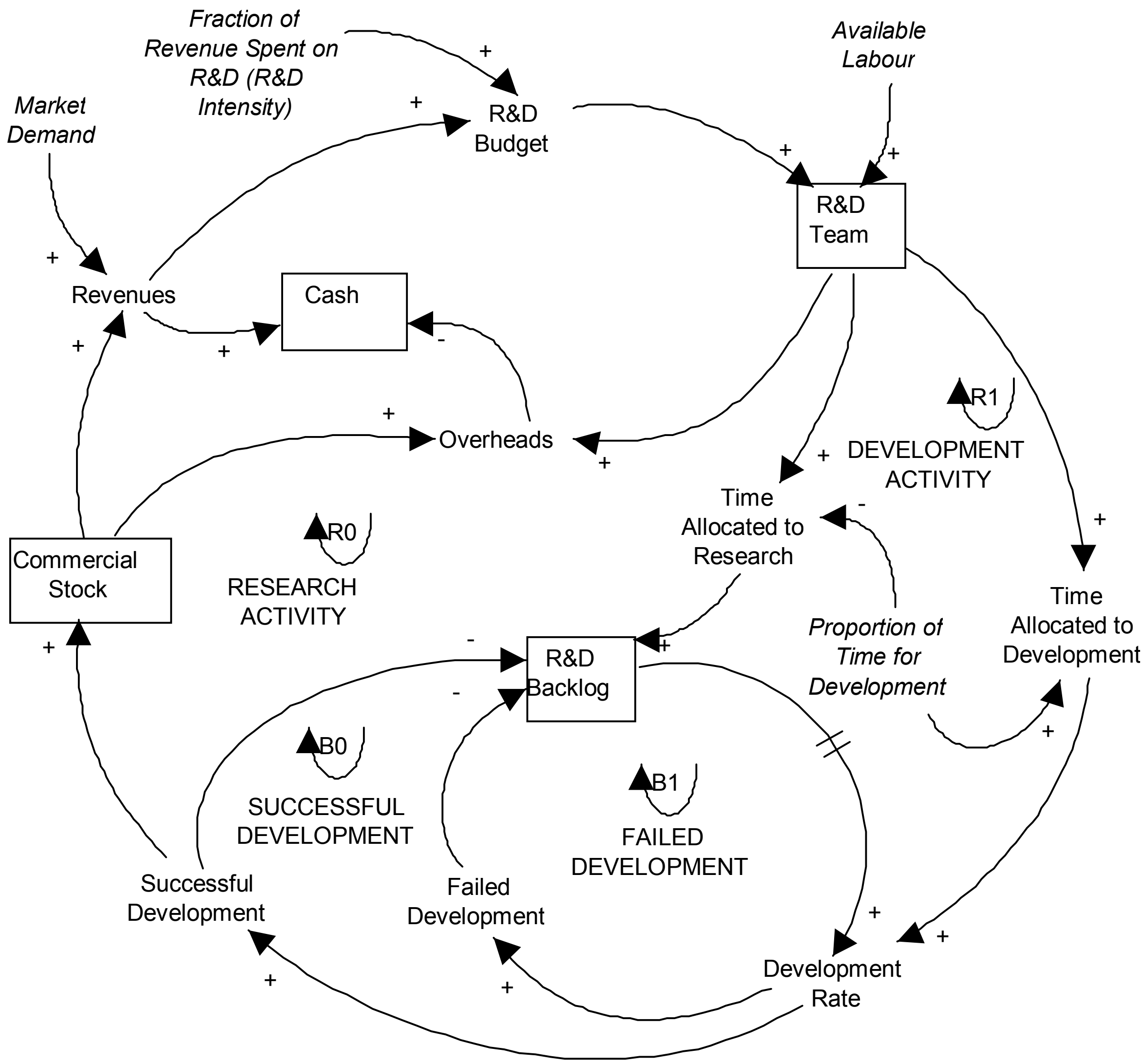

Figure 2: Simplified causal loop diagram of the R&D Model (B and R label balancing and reinforcing loops respectively).

There are four points of leverage indicated in this diagram where management change can be employed: extent of market demand, R&D intensity, availability of labour and proportion of staff time allocated between R&D activities. Market demand and availability of labour are assumed to be wholly exogenous to a firm's operations (although in reality a firm's reputation can drive up demand for transaction or employment), whereas R&D intensity and the amount of staff time allocated between separate R&D activities are policies which are endogenous to the firm's business model.

It seems evident that market demand is the most significant of these drivers, irrespective of whether the firm operates a technology push or market pull strategy. A trade-off is required here between supply and demand. Having too small or large a Commercial Stock (technology offering) will result in under or over-supply. If revenue maximisation is to be achieved, then the size of the market demand must be matched by the number of commercial offerings. This is far from a cake-walk, given that this business model is characterised by multiple feedbacks and delays, and to add to the complexity, the level of turbulence in the industry environment.

Developing a set of congruent and coherent strategies requires that these leverage points be examined in unity. In order to align supply and demand, an integrated set of high-level decisions is called for. This requires the sufficient development of a number of resources across the R&D function, *i.e.* the stocks resident within the model. This can be achieved through managing the internal drivers of change, and pre-empting and responding to the external drivers. The R&D budget needs to be supported; pool of potential labour has to be tapped in order to maintain a sufficient research team; and the workloads of the R&D Team have to be balanced between conducting the research, and facilitating its subsequent development.

The Research and Development Simulation Model

The R&D simulator has been developed and tested using the iThink™ (system dynamics) software. It contains three sectors: R&D Pipeline, R&D Team, and Finance.

Research and Development Pipeline Sector

R&D projects in the firm progress along a pipeline (Figure 3). Herein the term projects is used rather generally, in some industries the Commercial Stock may be measured in end products, core products (Prahalad and Hamel, 1990), portfolios of patents *etc.*, what is important is that it is possible to characterise a unit of Commercial Stock in terms of average revenue earned per year per unit of Commercial Stock. The R&D Backlog is increased by research activity and is depleted by successful and failed development activity, and the atrophy of non-progressed research. Successful Development increases the Commercial Stock (technologies available for commercial exploitation). Commercial Stock Obsolescence depletes this stock. This is a proportion, and is based on the commercial life of a technology or product in the industry.

The dwell time for projects in the R&D Backlog is governed by feedback processes. The R&D Backlog per Team Member is used as a determinant of Work Effectiveness (proxy for team productivity). Work Effectiveness then dictates the Development Rate. For simplicity the CLD (Figure 2) shows a positive link between the R&D Backlog and Development Rate; however the actual model used has this as a bipolar relationship. A table function is used to represent the inverted U relationship between work effectiveness and R&D Backlog; such a relationship between performance and stress levels being well known (George and Jones[Ch9], 1999). In this portion of the R&D system, one is seeking to instrument policies that will align the flow of projects between R&D and commercialisation. This can be achieved through up to two managed interventions (policies):

- change the size of the R&D Team (this stock is not enclosed within the R&D Pipeline Sector but acts as a sector input), and/or
- shift the allocation of staff time between research and development activities.

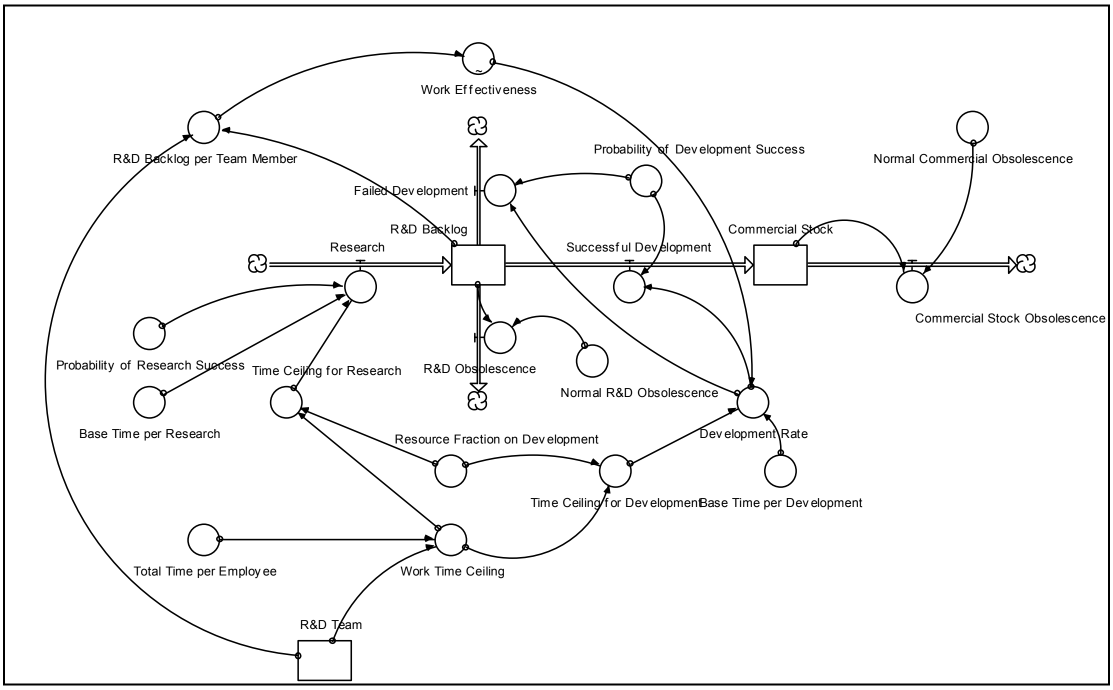

Figure 3: Stock-flow diagram of the R&D pipeline sector

Research and Development Team Sector

The R&D work in the firm is carried out by the R&D Team (Figure 4). R&D employees progress along a short pipeline. The R&D Team is increased by recruitment, and depleted by staff leaving the team. If there is a shortfall between the desired and actual size of the R&D team, then the firm recruits from the labour market. The number of R&D employees depends upon the proportion of revenues that the firm chooses to re-invest in the R&D function (R&D intensity). The R&D sector of the system is characterised by target-seeking behaviour. The staffing policy is predicated around the maxim, the higher the R&D intensity, the more R&D staff required in the team *i.e.* in increasing R&D expenditure, staff and all associated costs are increased proportionately; the method of working is not changed. The ability to fund a growing R&D staff is dependent upon revenues, a rate that lies beyond this sector but within the wider model.

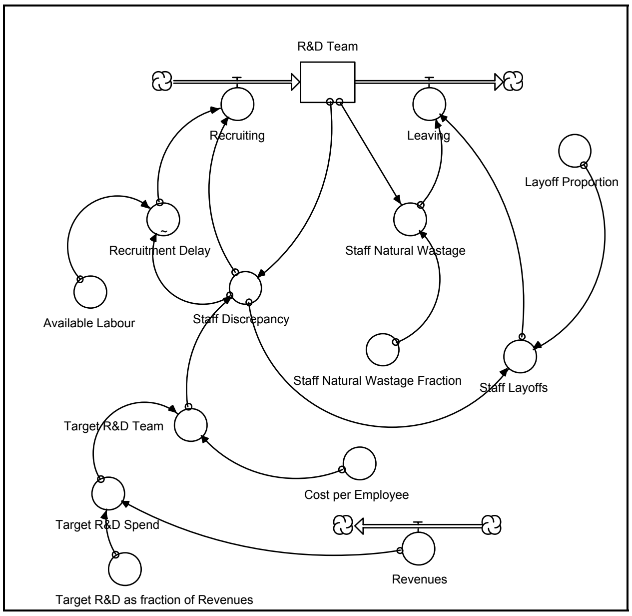

Figure 4: Stock-flow diagram of the R&D team sector.

Finance Sector

Cash moves along a short pipeline (Figure 5). The firm's stock of Cash is increased by incoming revenues from sales, and is depleted by R&D and other operating expenses incurred. The algebraic difference between revenues and expenses gives (instantaneous) profit. The R&D costs are proportional to the size of the R&D Team. The market dynamics will dictate the supply-demand relationship. Policies which can be controlled in part within the sector are the R&D employment costs and the other operational costs incurred across the firm.

There are three drivers in this sector sitting outside the control or direct influence of the R&D policy-maker which influence how Cash accumulates or depletes. These are the Market Demand for the available technologies, Base Revenue per Commercial Project (perfect revenue achievable assuming there is an infinite market demand) and Normalised Revenue per Commercialised Project (revenue per sale based upon the discrepancy between market demand & size of the firm's commercial technology stock). Explicitly Revenues is the product of Commercial Stock, Normalised Revenue per Commercialised Project[1] and Base Revenue per Commercial Project.

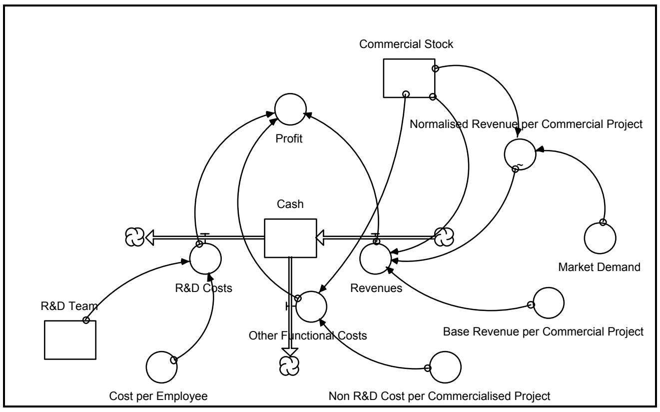

Figure 5: Stock-flow diagram of the finance sector

Research and Development Policy Analysis

Policy analysis helps the model user to understand why a system behaves in a certain way (Coyle, 1996). Policy experiments with system dynamics models are used to help design the best possible robust behaviour into the system under study. There are very many possibilities open to the model user (policy-maker), and there is no way of knowing in advance which will give the best overall performance in the system. The only way to progress is to experiment with different policies with the intention of designing a scenario which suggests the best outcome, that is the control of any undesirable behaviour within a system. The policy alternative must of course be implementable in the real system.

One way that policy analysis can be conducted is through making modifications to the numerical parameter values of the simulation model, so as to reflect different scenarios; then compare and contrast behavioural trajectories and numerical outputs. These activities should help to find better simulated results. This simplified R&D model contains a limited number of policy parameters, making a coherent analysis relatively straightforward. The process of experimentation can render a clear understanding of why the model behaves as it does. Multiple policy parameter changes will offer more verisimilitude, and may facilitate the generation of deeper insights and understandings.

It is not enough to know that certain policies improve behaviour. The simulation model user needs to know why that behaviour happens. Otherwise, they will not think about implementing the policy decisions in the firm. For this to be achieved, the model user must at least understand the principal feedback structure of the model (as outlined in Figure 2). Also, they must always be aware of the limitations of the policy experimentation design. A mix of policies in a simulation may show a very desirable outcome but it may be impossible to translate these changes into the real system. Therefore, the policy parameters must be kept within clearly achievable bounds.

Recent Changes in the Consumer Electronics Market

The falling price of consumer electronics in the UK has buoyed consumer demand (Harvey, 2004). Bigger manufacturers have ramped up their production to meet this demand and have benefited from economies of scale but at the same time the retail cost is no longer reflecting the cost of consumer electronics. Higher prices in the past allowed the R&D costs to be recuperated. Given this increased intensity of market competition, can consumer electronics firms maintain sufficient revenue streams and profit from improving R&D strategies alone or it is necessary to also continue to drive down manufacturing costs?

The Research and Development Policy Designs and their Ability to Accommodate Radical Market Change

Up to year three a stable relationship exists between market and firm in the simulation. The market demand is static and predictable. This allows the firm to maintain a steady flow of R&D projects through to commercialisation. The simulation model runs in a steady-state or equilibrium. At year three, the market experiences an episodic shift. There is a simultaneous step increase in 'Market Demand' (100%) and a step decrease in 'Base Revenue per Commercial Project' (25%) causing a state of disequilibrium. The market now requires 'more for less'.

The electronics firm has to decide how to respond to these new market conditions. There are a number of policy alternatives that they could employ as a means of stabilising or even growing profit in response to this market discontinuity. Given the complexity associated with aligning R&D, commercialised products and market demand, the firm would benefit from looking at this problem in its totality. Using a system dynamics simulation allows an exploration of longitudinal change in performance and capabilities under different sets of policy combinations.

A range of alternative policy confluences are explored in the five scenarios outlined below. The efficacy of these strategic decisions is mapped out over 20 years of simulated time. A range of indicators of the firm's performance and capabilities are monitored during each simulation run.

The policy analysis is designed to identify R&D policies which result in improved performance within the firm as measured across a range of indicators. A number of key metrics are selected to allow behavioural and numerical analysis of simulation performance. The final values and trajectories of these are noted for each simulated scenario and used for comparison. The selected indices are defined as follows:

> **Profit** – The positive financial gain from the business operation after subtracting the R&D and operating expenses.
> **R&D Team** – Personnel responsible for the R&D activities.
> **Normalised Revenue per Commercialised Project** (NRPCP) – Inverse S-shaped relationship between the firm's supply of commercial technology stock, and the market demand for those technologies. If the ratio between these is high, then the NRPCP is low. The higher the NRPCP, the higher the revenue accrued per commercial technology stock.
> **Work Effectiveness** – The efficiency (or productivity) with which the average R&D member of staff works. As discussed earlier, the relationship between work effectiveness and the R&D Backlog per R&D Team is bi-polar. The optimum work effectiveness is evident where neither work stretch (staff gold plating or boredom) or work compression (staff under intense stress) is manifest.

In reaction to the market changes, the R&D policy maker could act in a number of ways. A range of policy modifications can be explored and their ability to deal successfully with a discrete market change measured and evaluated. Five broad policy scenarios are explored using the simulator:

- Scenario 1 – no change;
- Scenario 2 – greater R&D intensity;
- Scenarios 3a and 3b – balancing resources and work loads between the respective R&D activities;
- Scenario 4 – lower R&D intensity.

These policy experiments have been set up as a means of capturing insights into the range of behaviours that the R&D system is capable of, with the desire to design policies which may render improved performance to technology firms operating under such business conditions.

Scenario 1: Business as Usual (Base Run)

The first scenario to be explored is titled 'business as usual'. This consists of keeping all policy decisions as fixed throughout the course of the simulation run, i.e. the firm does not modify its policy decisions in the face of this discrete shift in market demand. This scenario is set as the base run for the subsequent policy tests, and alternative scenarios are played out with a view to discovering if more desirable behaviour can be exhibited by the simulation model.

Figure 6 shows that if no alternative action is taken in response to the new conditions, then profit declines. This decline results from a diminished flow of R&D projects through to commercialisation. Declining revenues have resulted in lower absolute investment in the R&D team. As this capability reduces, then the flow of R&D projects is arrested. The NRPCP or ability of a given commercial technology to provide a return increases as the gap between market demand and the commercialised technologies extends. Unfortunately, as the output of the firm is diminishing so is its means of covering its operational overheads. The work effectiveness of team members remains constant as the volume of R&D work and size of the team declines together. Although the firm has not entered a free-fall, it is moving towards a slow death.

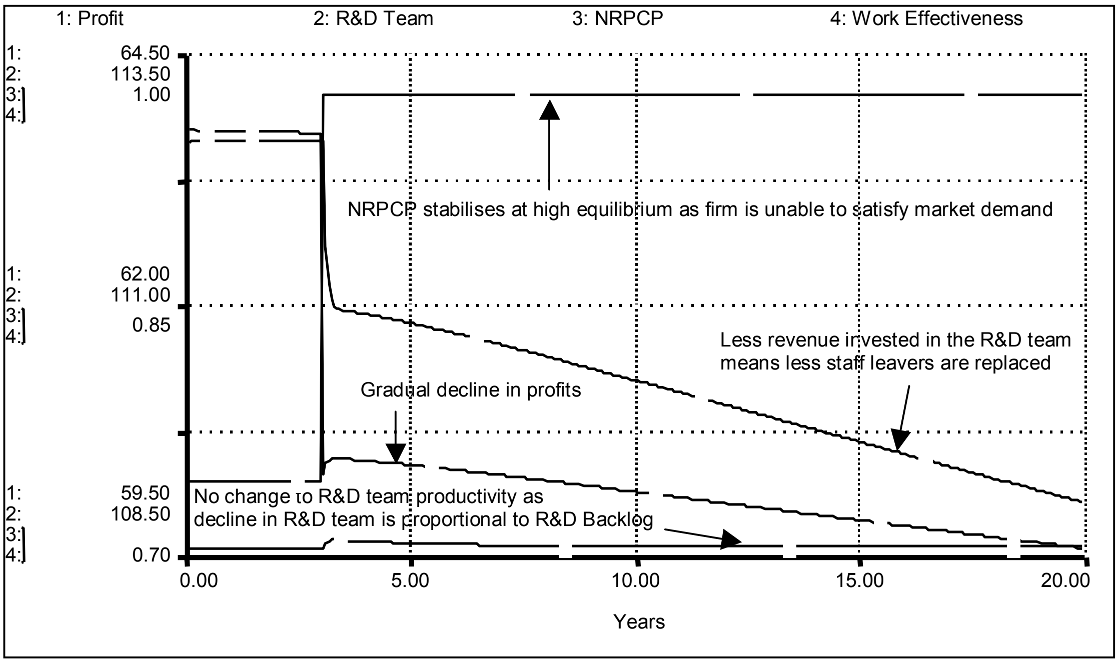

Figure 6: 'Business as usual' with no new response to market change

Scenario 2: Higher R&D Intensity

In the 'business as usual' scenario where no policy modifications are instituted, the performance of the simulated firm slowly deteriorates, with nearly all outputs exhibiting undesirable behaviour. The policy makers may see fit to improve the R&D system through boosting the amount of R&D activity. The 'higher R&D intensity' scenario shows the effect of doubling the proportion of resources committed to the R&D function in comparison with the base run, whilst keeping all other policies invariant.

Figure 7 shows a greater deterioration in system performance than seen in the base run. Profit stabilises then collapses into losses. This decline results from too rapid a growth in the flow of R&D projects through to commercialisation. Over time, an over-supply of commercial technologies to the market emerges and revenues consequently decline. Lower absolute investment in the R&D team occurs, and as this capability reduces, the flow of R&D projects slowly diminishes. The NRPCP collapses due to the market over supply. The work effectiveness of team members recovers as the volume of R&D backlog per team member grows to a more optimal level. If the firm cannot turn around the financial loss making then it may not survive over the 20 simulated years.

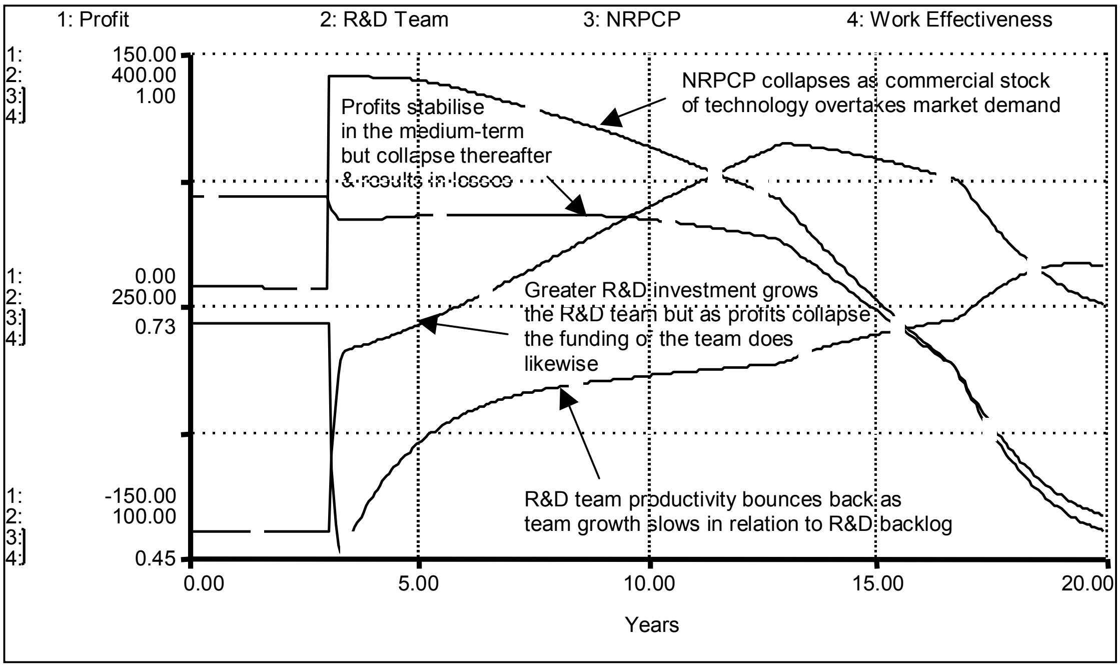

Figure 7: 'Higher R&D intensity' as a response to market change

Scenario 3a: More Research and Less Development

In the 'higher R&D intensity' scenario the performance of the firm greatly deteriorates across most measures from the medium and into the long-term. An alternative scenario to heavily financing the growth of the R&D function may be to make better use of existing resources through better allocation of staff time between respective R&D activities. The 'more research and less development' scenario shows the effect of modestly increasing the proportion of resources committed research at the expense of development in an effort to boost the backlog of R&D ready for commercialisation. All other policies remain fixed.

Figure 8 shows a general improvement in the system as compared to the base run. Profit grows consistently and, after a period of time, exceeds the initial profit. This improvement results from a steady growth in the flow of R&D projects through to commercialisation. Over time, the stock of commercial technologies gradually approaches market demand and revenues remain strong but grow at a lessening rate. As expected, the NRPCP declines slowly as the market is better satisfied. The work effectiveness of team members approaches an optimal level (i.e. a good balance for the team between trying to compress their work or stretching it out). The health of the firm looks to be secure under these market conditions into the long-term.

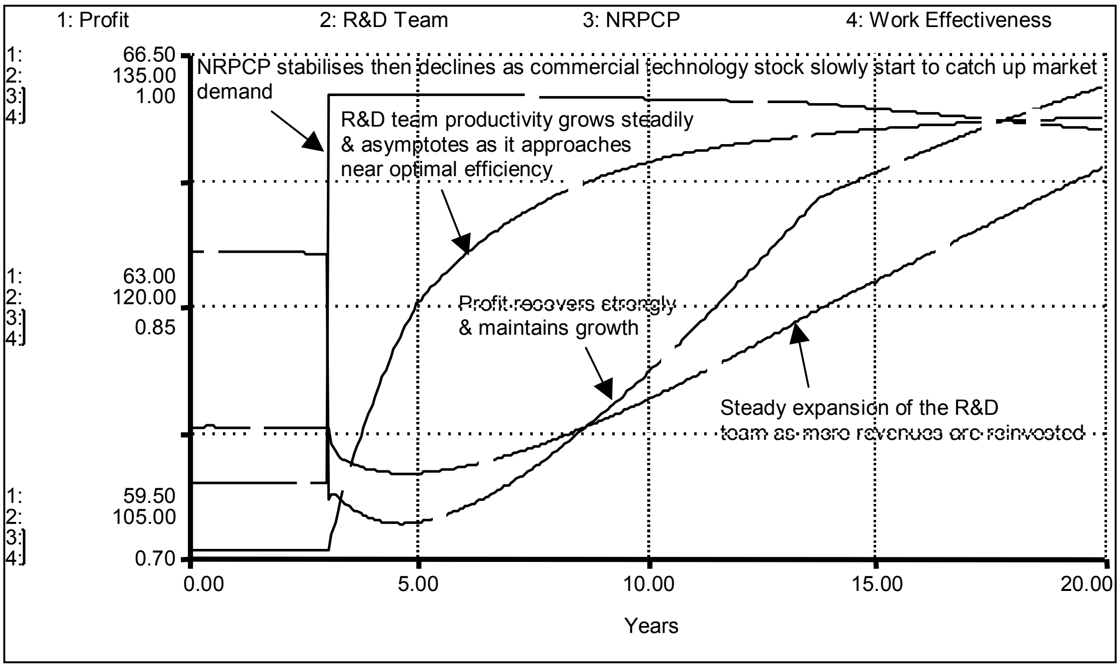

Figure 8: 'More research and less development' as a response to market change

<u>Scenario 3b: Even More Research and Even Less Development</u>

In the 'more research and less development' scenario noticeable improvement to performance are achieved. Can further improvement in system behaviour be attained through stepping up the proportion of research further? The research over development effort is increased further in the 'even more research and even less development' scenario. The other policies are held steady.

Figure 9 shows poorer system behaviour than the previous scenario runs. Profits do stabilise in the medium-term but are not sustainable in the long-term, and thus collapse. A bottleneck develops in the project pipeline as the flow of successful development project through to commercialisation declines, resulting in R&D backlog building up. As the revenues diminish, so does the level of R&D investment, and the size of the R&D team begins to fall. The commercial output of the firm diminishes and market demand is satisfied even less resulting in the continued rise in NRPCP. Work effectiveness improves with the growing R&D backlog but after a point, the backlog grows to such an extent that the R&D team are put under undue stress to develop the backlog into commercial technologies, and consequently productivity collapses.

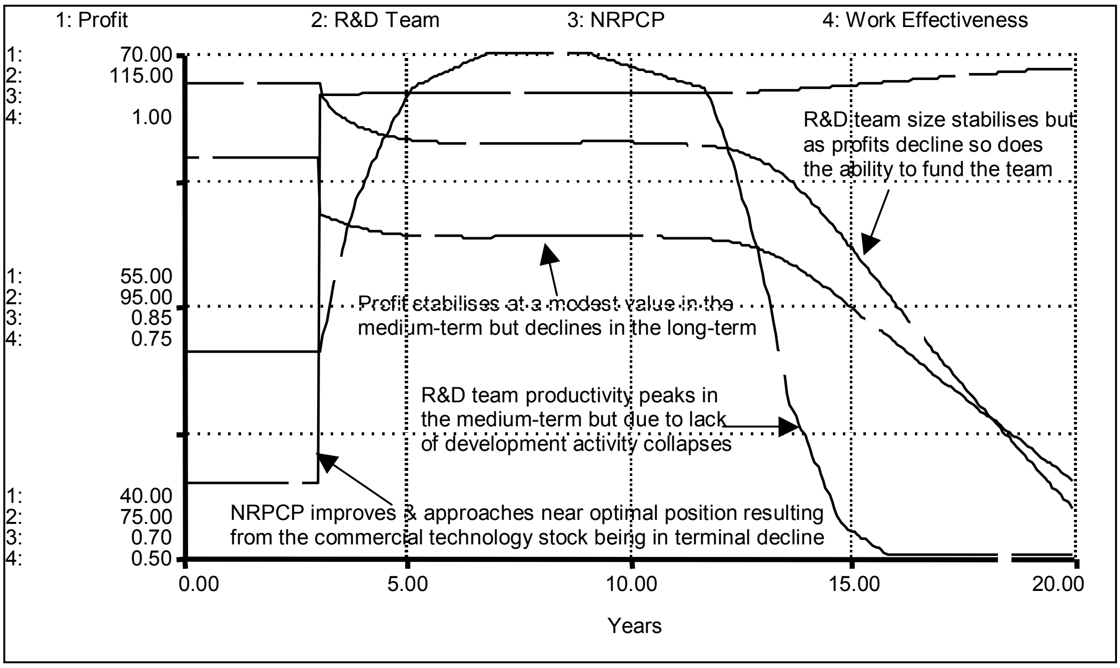

Figure 9: 'Even more research and even less development' as a response to market change

Scenario 4: Lower R&D Intensity with Modest Development

Can the policy makers offset the fall in base revenues by reducing the R&D intensity to a lower level whilst maintaining a moderate amount of development over research allocation? This policy confluence is tested in the 'lower R&D intensity with modest development' scenario.

Figure 10 shows a greater deterioration in system performance than seen in the base run. Profit recovers temporarily but then declines into the long-term. A diminishing R&D team reduces the flow of R&D projects through to commercialisation. Over time, an under-supply of commercial technologies to the market emerges and revenues consequently decline. This results from a lower relative and absolute investment in the R&D capability. The NRPCP improves due to the market under-supply. Although work effectiveness improves over the medium into the longer term, by year 18, even this starts to decline as the R&D team depletes at a greater rate than the R&D stock is being worked down. If the firm can not turn around the ever reducing profits, then its operations are not sustainable in the long-term.

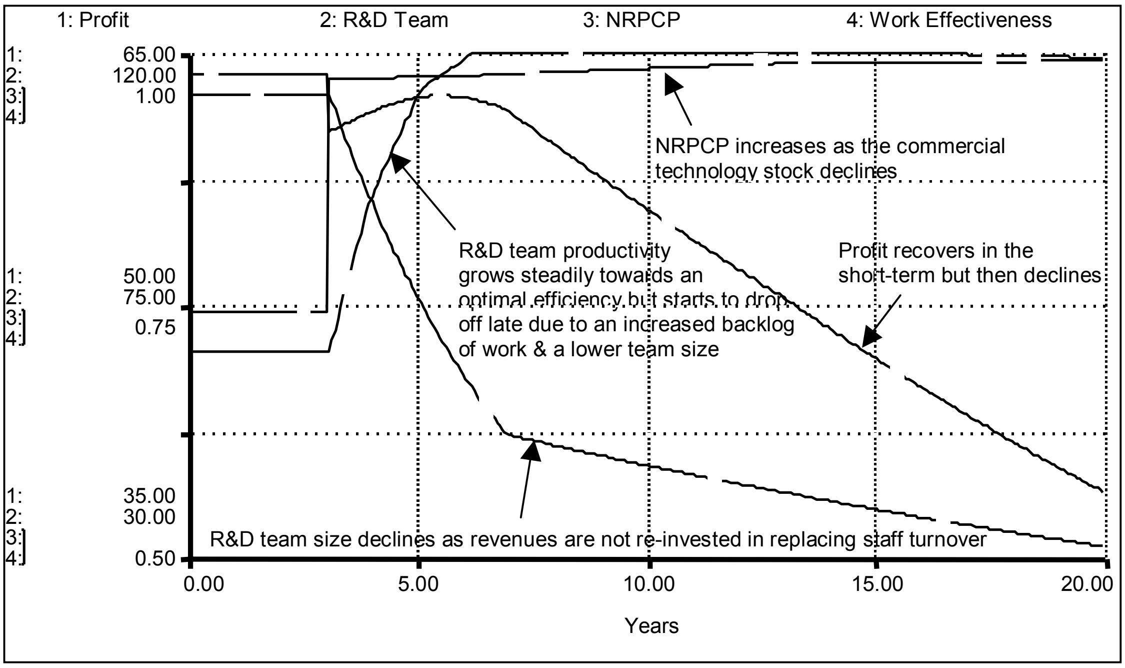

Figure 10 'Lower R&D intensity with modest development' as a response to market change

Summary of R&D Policy Options

The policy options or experiments set up for the different scenarios are summarised in Table 1. In Scenario 1 all policy decisions are unchanged in the face of the market shift. The R&D intensity is ratcheted up in Scenario 2 in an effort to satisfy the new market demand. In Scenarios 3a and 3b, an effort is made to balance resources and work loads between research and development activities. Finally, the effects of low levels of R&D intensity are evaluated in Scenario 5.

	Target R&D as Fraction of Revenues	Resource Fraction on Development	Non-R&D Cost per Commercialised Project (£M)
Scenario 1	0.05 (Medium)	0.7 (High)	20 (High)
Scenario 2	0.10 (High)	0.7 (High)	20 (High)
Scenario 3a	0.05 (Medium)	0.6 (Medium)	20 (High)
Scenario 3b	0.05 (Medium)	0.5 (Low)	20 (High)
Scenario 4	0.025 (Low)	0.6 (Medium)	20 (High)

Table 1: Summary of policy options selected for the scenario tests

	Profit (£M's)	Profit per R&D Team Member (£M/Employ.)	NRPCP	Work Effectiveness
Scenario 1	59.54	0.55	0.98	0.70
Scenario 2	-127.43	-0.51	0.47	0.77
Scenario 3a	128.14	1.94	0.95	0.96
Scenario 3b	44.35	0.56	0.99	0.50
Scenario 4	38.70	1.23	0.99	1.00

Table 2: Summary of business performance for selected scenarios (final values)

	Profit (£M's)	Profit per R&D Team Member (£M/Employ.)	NRPCP	Work Effectiveness
Scenario 1	4	6	3.5	5.5
Scenario 2	7	7	7	4
Scenario 3a	1	1	5.5	2.5
Scenario 3b	5	5	1.5	7
Scenario 4	6	2	1.5	1

Table 3: Ranking of business performance indices for selected scenarios

The business performance of the firm across the different scenarios is described in Table 2. Final values for the end of the simulation for profit, profit per R&D team member, normalised revenue per commercialised project (NRPCP) and work effectiveness are presented in the table. Table 3 ranks performance for the chosen metrics. Scenario 1 does not render a particularly desirable outcome (Figure 6). Scenario 2 provides the poorest all-round performance, with particularly dismal profit, profit per team member and normalised revenue (Figure 7). As far as profit and profit per team member is concerned, Scenario 3a indicates superior performance (Figure 8), while poorer results are attributed to Scenario 3b (Figure 9). Scenario 4 provides the highest performance in terms of normalised revenue and work effectiveness, a good profit returned per R&D employee but a poor absolute profit (Figure 10).

Which Set of Policies to Elect for and Why?

There are two clear dichotomous alternative solutions to the market dynamics problem. Either 'go for growth' employing the R&D policies indicated in Scenario 3a or 'downsize' the R&D activities as demonstrated in Scenario 4.

There are a number advantages associated with growing and maintaining a strong R&D capability, which include:

- retaining a skilled team as an insurance against having to source R&D staff in a tight labour market;
- having the R&D resources available to respond to, influence or even create market demand;
- permitting the firm to engage in higher value upstream business activities; and
- allowing the firm to lobby government, quasi-government and trade associations more powerfully.

There are also advantages coupled with the act of downsizing the R&D function, which include:

- lower R&D overheads;
- lower organisational complexity facilitating more transparent decision-making; and
- faster response to an actual or anticipated market change.

Which of the two desirable R&D strategies to adopt (*i.e.* grow or downsize R&D capability) will lie with the key decision-makers within the firm. Principal consideration should be afforded to how congruent the chosen R&D strategy is with the long-term strategic business objectives of the firm.

There are a number of limitations to scenarios played out in this insight model, based around the tight model boundary or delimitations. The model structure is not able to reflect a firm's ability to influence the level of demand for their product through marketing, distribution & technological features, nor has a change in operational costs been investigated. *Work effectiveness* has been included in the model as a function of R&D Backlog per employee and this in turn affects development rate. However to more fully capture the important human dynamics intrinsic to any socially constructed organisation, it will be necessary to build knowledge, skills, attitudinal & behavioural factors into the model [Roy and Mohapatra, 1994; Moizer and Towler, 2003].

Future Work

There are two clear and related possibilities that the investigated scenarios did not consider. Scenario 2 showed some initial advantage from increasing the R&D Intensity, but this eventually led to an oversupply in the Commercial Stock, introducing more variables rather than parameters seems reasonable, particularly allowing the R&D Intensity to change with time. Following on from this, decision rules to continuously change the R&D Budget based upon cash, profit, revenue *etc.*, could be considered. For example, a change to the CLD (Figure 2) of including a negative link between Overheads and R&D Budget introduces several additional balancing loops into the structure.

The current model has consisted of synthetic data within a specific industrial context. Moving the model into other industry contexts will, as well as changing industrial parameters such as obsolescence rates, require some structural changes. The most obvious of these are:

- the number of phases in the pipeline (*i.e.* the required level of disaggregation),
- learning and motivation co-flows allied to the R&D pipeline;
- additional inflows and outflows (specifically buying or selling technologies along the pipeline), and
- separating product and process R&D (*e.g.* R&D to reduce Non-R&D Costs per Commercialised Project)

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[1] It is assumed that it is possible to characterise each unit of Commercial Stock in terms of revenues earned per year per unit of Commercial Stock:

Revenues = Commercial Stock x Base Revenue per Commercial Project x NRPCP

The NRPCP is described by a table function and is based upon the discrepancy between Market Demand (allowing growth and decline to be included in the model) for the industry's technology and the size of the firm's Commercial Stock. Depending upon the detail of this S-shaped curve this may or may not lead to Revenues monotonically increasing as the company increases its Commercial Stock (Figure 11).

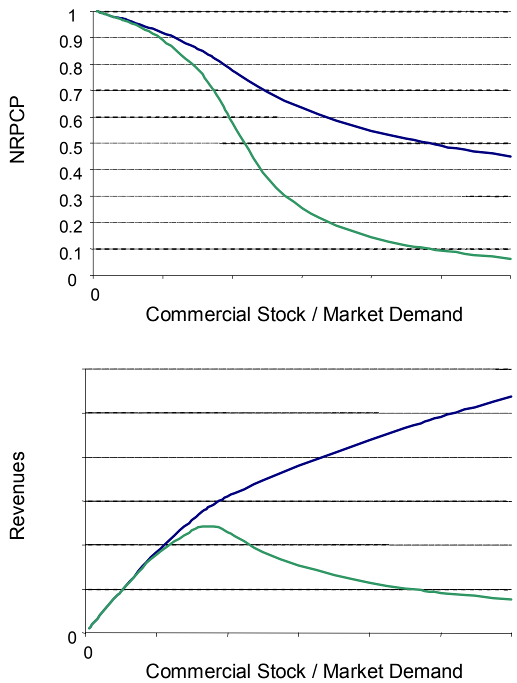

Figure 11: The relationship between NRPCP and Market Demand.

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