This is to certify that the
dissertation entitled

REAN INVESTIGATION OF THE INTERACTION OF
ADVERTISING, PRICING AND QUALITY ON SALES
RESPONSE

presented by

ERIC CHARLES JACKSON

has been accepted towards fulfillment
of the requirements for the

Ph.D degree in Department of Marketing and Supply Chain Management

Ram Narayanan.

Major Professor's Signature

6/2/04

Date

AN INVESTIGATION OF THE INTERACTION OF ADVERTISING, PRICING AND QUALITY ON SALES RESPONSE

By

Eric Charles Jackson

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

Department of Marketing and Supply Chain Management

2004

AN INVE

Mu

to consum

predetermi

informatio

attempting

company

process to

and Mend

profile mig

The NGM

quality as

This disse

Fi

NGM mo

product a

disaggrega

ABSTRACT

AN INVESTIGATION OF THE INTERACTION OF ADVERTISING, PRICING AND QUALITY ON SALES RESPONSE

By

Eric Charles Jackson

Much information about product quality diffuses into the market place via consumer to consumer communication and other mechanisms that are not directly connection to predetermined corporate promotional policies. This fact raises questions about how the information that has diffused into the market interacts with active corporate policies attempting to communicate information to consumers. It also creates questions about how a company might use the quality aspects of its products to take advantage of this diffusion process to maximize its profitability. The NGM model was developed by Narasimhan, Ghosh and Mendez (1993) to examine this question by considering how improving a product's quality profile might impact the total profits a company might realize over the life of a durable good. The NGM model did this by using the product price as an optimal control variable and using quality as a factor impacting purchasing as quality weighted goods diffuse into the marketplace. This dissertation will extend the NGM model in three ways.

First, the original NGM model has no explicit competition for market share. In the NGM model competition is implicit. The current work explicitly incorporates a second product as competition to the first product in the marketplace. Second, the current work disaggregates quality into two factors and examines how quality affects sales in two ways. The

improvem

incorporat

informat

Pra

policy decis

existing co

their marke

levels of a

information

potentially

original NGM model examines quality as a single factor. In this work quality is considered both in terms of improvements generated by a continuous quality improvement mechanism and quality improvements made via a discontinuous mechanism, e.g. designed product improvements such as new features. The third extension to the NGM model is to explicitly incorporate the effect an advertising policy has on sales as well the impact that policy has on information diffusion.

Practitioners are expected to be able to use the results from this dissertation to assess policy decisions in two ways. First, they can compare and contrast their quality strategy with existing competition in their market segment. They can also consider how a new entrant into their market might impact their existing quality strategy. Second, they can consider different levels of advertising expenditures within the context of quality information diffusion. This information should suggest the best time periods to implement planned model changes and a potentially more efficient use of advertising expenditures.

DEDICATION

To my parents Rita and Charles Jackson who made the daydream a possibility.

To my wife, Alison, and my children Danielle Ann and Christopher Louis, who made the possibility an attempt.

To my committee who made the attempt a reality.

As always
to ackno
appreciate
help. How
Special th
of duty, K
whose se
everything

ACKNOWLEDGMENTS

As always in a work of this nature there are too many people making significant contributions to acknowledge each individually. All of the contributions from all people are greatly appreciated and the work could not have been completed nor even attempted without their help. However, beyond this there are some specific contributions that need to be highlighted. Special thanks go to: Ram Narasimhan who showed patience well above and beyond the call of duty, Ken Boyer whose faith and support were important beyond measure, Srinivas Talluri whose sense of humor kept despair at bay and Anthony Ross whose enthusiasm kept everything in perspective.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

adapti

produ

consu

either

result

order

gross o

1999). (

evolve

that the

noting t

that hav

number

from th

by anoth

one reas

to maxim

Resourc

CHAPTER 1

Introduction

Firms and consumers exist as complex adaptive agents in an ever changing and adapting environment. Firms are continuously modifying their products in the hope that their products will become more attractive to consumers than their competition's products. In turn consumers continuously change their expectations of the performance of products due to either new product attributes or information gleaned from other information sources. The result of this bidirectional pressure on products is that functionality that once qualified as an order winner ceases being an order winner and becomes an order qualifier over time. As a gross overview this type of complex adaptive system is well established (Axelrod and Cohen 1999). Of greater interest to practitioners than the system is how this pressure on products to evolve develops. An understanding of this pressure allows firms to modify their policies so that they may influence the process.

The adaptability of a firm has limitations. David J. Teece (1985) emphasizes this by noting that the amount or level of a firm's flexibility is constrained by irreversible investments that have been made by the firm in the past. Furthermore, a firm's flexibility is limited by the number of options available to it in its environment. Products that are too great a variation from the norm accepted by consumers might not be purchased as readily as products offered by another firm that have been accepted. This limitation of options for an existing resource is one reason why firms attempt to be selective in their resource selection and why they attempt to maximize the effectiveness of existing resources after their acquisition.

The acquisition and/or development of unique and rare resources is the basis for the Resource-Based View (RBV) of the firm (Wernerfelt 1984), (Barney 1991), (Wernerfelt 1995), mabi:

ied to

Priem

and va

quality

and he

interact

become

turn to

change

firms m

repairs.

praise p

commu

product

sway co

product

product

lead co

(Barney 2001). The difficulty in identifying what is a rare and valuable resource before its acquisition is problematic because of the limited ability of firms to predict the future. The inability to predict what will be valuable in the future, before the acquisition of a resource has led to some questioning of the Resource Based View of the firm. (Godfrey and Hill 1995; Priem and butler 2001). This inability to completely predict what resource will become rare and valuable in the future emphasizes the need for firms to use policies vis-à-vis price, product quality and advertising to sway consumers to select its products instead of the competition's and hence maximize the firms profit stream. Thus the need for firms to understand the interactions of their policies and the impact those policies have on consumer purchases becomes essential. As the policies influence consumer behavior pressure is applied back in turn to the companies to again adjust their policies.

One simple method firm's use to gaining an understanding of the pressures acting to change company policies is active or direct communication with consumers. For example firms might initiate opinion surveys or they could collect information with respect warranty repairs. Consumers on their part may contact support units at firms to voice complaints or to praise products. However, despite the availability of active communication channels passive communications are more pervasive and exert a great influence both on corporate policies and products, they are however, far more complicated.

Each factor, pricing, advertising and product quality, influences the other's ability to sway consumers in potentially subtle ways. High prices might signal consumers that the product quality is high relative to the competitions'. Too low a price for a particular level of product quality might lead to consumers either assuming that the quality level is low or it might lead consumers to purchase that product in lieu of a product the company has targeted for a market segment requiring a higher level of product quality (Desai 2001). Advertising might relate the information about product quality but it might be offset by a competitors advertising or it might lose its effectiveness after consumers become generally aware of the level. The interactions of the policies might be further complicated by the actions of consumers.

High adoption rates by consumers might be indicative of general enthusiasm for the product. This enthusiasm might lead to a rapid diffusion of positive information about the product into the marketplace. This rapid diffusion could signal an extremely effective advertising campaign or that the pricing policy of the product is such that the company might not be maximizing their profits. A rapid diffusion of information about the product quality might also lead to a reduced need for advertising of the product in question. It might justify a price increase. An understanding of these complex interactions will be of great benefit to firms in determining the policies that they need to adopt to maximize the profits generated by a product over its life. This work will examine the interactions of pricing, quality and advertising in a competitive environment and how changes in pricing, quality and advertising influence the maximum profits a firm can realize over the life of the product.

Product – Price Interactions

One factor influencing the profitability of a firm is the choice made by that firm relative to the levels of quality that it incorporates into its products (Jacobson and Aaker 1987; Ouchi 1982; Phillips et al. 1983). This might be interpreted as the firm's quality strategy. Armstrong and Vickers (2001) note that "...the strategy of a firm is to choose the level of that

strate

The

impro

discon

contrib

consur

evolvin

contin

Wheth

the co

so tha

realize

ability

that ju

consu

conclu

intrins

and pe

Amsn

utility or 'value for money' offered …."[1] When applying this statement to quality it suggests that there exists an optimum level of product quality for a given price to which a quality strategy should aspire.

The level of quality, like many other factors, may be changed by the firm over time. The firm may improve the quality it's offering through two distinct mechanisms. It might improve quality via continuous quality improvement strategy or it might make significant discontinuous improvements. While both of these types of quality changes are positive contributions any limitation are imposed due to consumer expectations. Every time a consumer purchases a product they reevaluate the product and their own expectations. This evolving expectation sets a new minimum level of quality for a product. This minimum level is continuously moving up. In other words, today's order winner is tomorrow's order qualifier. Whether a firm relies on continuous quality improvement strategy or on a discontinuous one the company must decide how to combine their chosen levels of quality with a pricing strategy so that they can utilize the interactions between price and quality to maximize the profits they realize over the market life of their product.

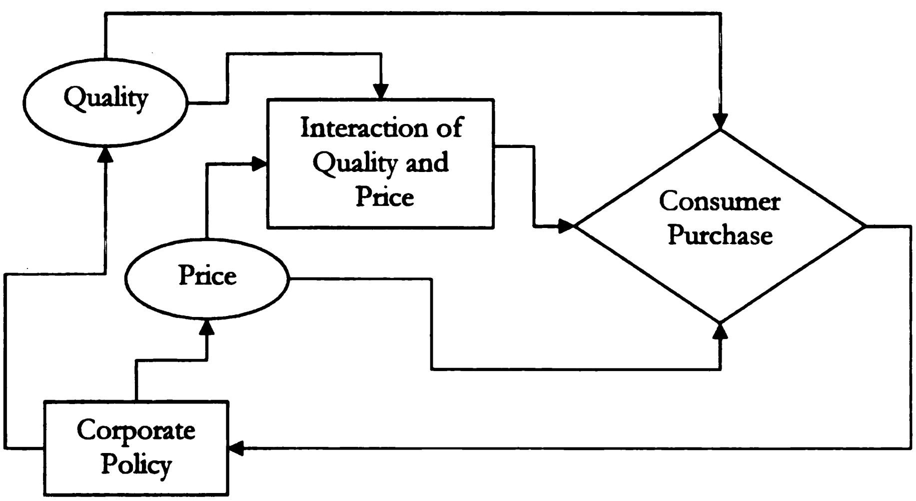
Much attention has been paid to the connection between price and quality and the ability of consumers to make quality judgments based on product price. Scitovsky (1945) noted that judging a products' quality by its price is a rational type of behavior. The idea that consumers used price as an indicator of quality was investigated by Leavitt (1954). He concluded that a product with a higher price is perceived in the market to have a higher intrinsic quality. More recently, a positive and statistically significant relationship between price and perceived quality was found by Rao and Monroe (1989). In another study performed by

---

[1] Armstrong M, Vickers J. 2001. Competitive Price Discrimination. *RAND Journal of Economics* **32**(4): 579-605

Irandoust (1998), a connection between pricing and quality was found by in the Swedish automobile market. Despite these indicators that consumers may be able to identify quality from a products price there has been research to indicate that they cannot.

Several researchers (Gerstner 1985; Riesz 1978; Riesz 1979; Sprokes 1977) have all found that that the ability of price to signal quality to the consumer was weak at best. Lichtenstein and Burton (1989) performed studies using both durable and non-durable goods in an effort to address how effectively price signals quality to consumers. They found that consumers' ability to identify quality from price is only moderate at best. However, they did find that consumers were able to more accurately identify a price quality relationship for non-durable goods than they were for durable goods. This interaction with its feedback loop to corporate policy may be conceptualized as in Figure 1.



Quality – Price Interactions and Consumer Purchase Decisions

Figure 1- Quality/Price Interaction

of adv

Produ

consum

that pr

sales ar

sales b

aspects

vital ma

attribut

sales. Tr

and the

attention

and Rob

(Nelson

Other factors naturally affect how consumers perceive the quality of a product. Prior experiences with the product or an earlier version of the product greatly impact a decision to purchase a product another time. Information from other consumers on their experiences with the product will sway a purchase decision. Information provided by the company in the form of advertising or promotion is factored into a purchasing decision.

Product – Promotion Interaction

The principal function of Promotion or advertising is to provide information to consumers about a company's product in such a way so as to sway the consumer to purchase that product. Lilien et al (1992) note that "...advertising is undertaken to increase company sales and/or profits over what they other wise would be. However, it is rarely able to create sales by itself. Whether the customer buys also depends on the product, price.....and other aspects of the marketing process." [2] This statement clearly shows that while promotion is a vital marketing function it is usually interacts with other factors. In other words, the product's attributes, its quality, and its pricing are factors that interact with advertising and influence sales. Therefore they have an impact on a company's promotion policy.

Advertising as a mechanism for transmitting information about the product's quality and the ability of consumers to interpret this information has been the focus of much attention in the literature.(Milgrom and Roberts 1987; Milgrom and Roberts 1986a; Milgrom and Roberts 1986b; Nelson 1974; Nelson 1970; Shapiro 1982)Of particular interest is Nelson's (Nelson 1974; Nelson 1970) division of goods into two different types those that consumers in the

to pr

may a

the ve

the att

of a pr

lifetim

discon

the rate

alter th

experien

experien

mechan

commu

these in

time. In

policies

Lilien, G

Prentice

may be able to identify by inspection of the product, what Nelson calls search goods, and those that the consumer cannot assess before they have acquired the product, experience goods in Nelson's terminology. This division may be extended into different attributes found in the same durable good. The fit and finish of an automobile and the ability of the power train to provide performance over an extended period of time for example. These facets of quality may also be considered in terms of their improvement functions. Fit and finish improves with the volume of units produced. The more units are produced the greater the level of quality for the attribute because of the learning curve in production. Improvements in experience facets of a product depend on engineering improvements that are designed into the product over its lifetime. The first may be seen as a continuous improvement factor and the latter as a discontinuous improvement requiring effort above and beyond production practice.

In the context of search goods and experience it may be seen that advertising can alter the rate at which information about the product diffuses into the market place but it cannot alter the consumers experience with the product. It is only possible for consumers to gain experience information after they have purchased the product. Once consumers have experienced the quality of the product information about it is diffused into the marketplace via mechanisms that the firm has no control over. That is, direct consumer to consumer communication or the memory of the experience retained by the consumer. As a result of these interactions promotion or advertising may begin to lose some of its effectiveness over time. In this context it becomes necessary for firms to adjust their advertising and quality policies in such a way so that the body of information accumulated by consumers continues to

[2] Lilien, Gary L., Philip Kotler, and K. Sridhar Moorthy (1992), Marketing Models. Englewood Cliffs, New Jersey: Prentice Hall. pp263

advert

Wolfe

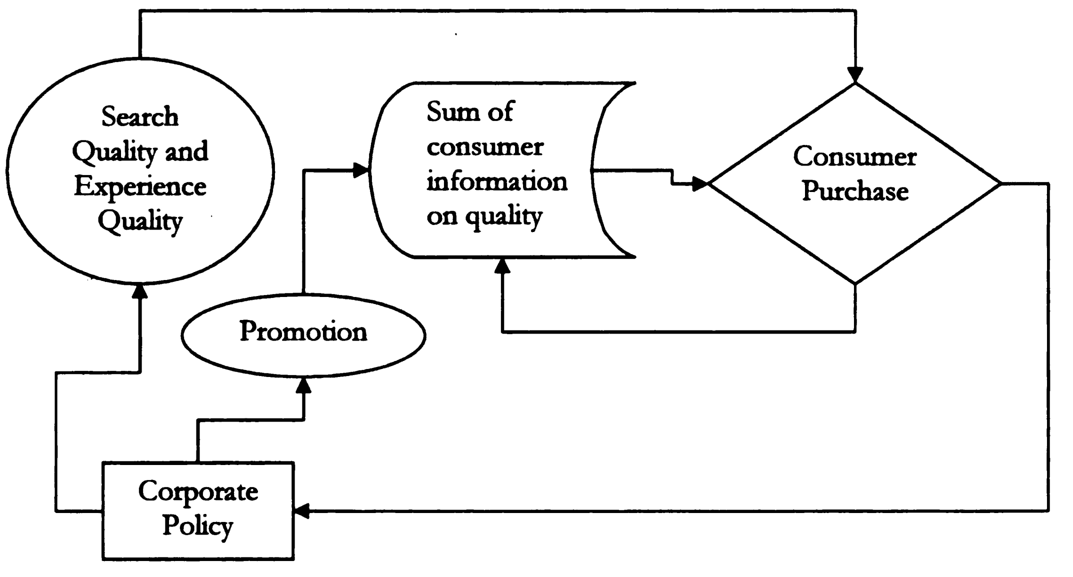
bounc

from

mark

a qua

positively influence sales and therefore profits. This feedback loop may be conceptualized by Figure 2.



Quality – Promotion Interactions and Consumer Purchase Decisions

Figure 2 – Quality/Promotion Interactions

Another factor influencing the amount of impact advertising has is the fact that advertising has a saturation level and is forgotten after a period of time (Little 1979; Vidale and Wolfe 1957).

These facts influence corporate policy in that the value of advertising has an upper bound beyond which there is no value in spending more on advertising and that the returns from any given advertisement diminishes over time. If the diffusion of product quality into the market place has a longer influence it may be possible to supplant the value of advertising with a quality policy over the long term.

comp

pricin

fact n

prom

durab

Resea

firms

import

how qu

may no

a whol

dynami

underst

influen

compe

Competition

Another major factor influencing consumers' purchases is the presence of a competitor in the market place. Both the pricing policies of a firm's competition and its own pricing influence the demand for its product (Desai 2001) and thereby its own profits. This fact necessitates the addition of competition into any effort to understand the interactions of promotion, product quality and price on the profitability a firm may realize over the life of a durable product.

Research Motivation

Price, quality levels, and advertising expenditures are three aspects of competition that firms have direct control over. As such their adjustments as strategic levers are vitally important to the success of the firm. While valuable information may be collected by studying how quality and advertising individually influence the optimal price of a product the results may not be the same when interact. This suggests that a greater understanding of the system as a whole may be developed by considering them together. This dissertation will develop a dynamic game incorporating these factors together in a competitive environment so that an understanding of their interactions may be developed.

In particular the interactions of advertising and quality, and how this interaction influences the optimal price trajectory used to maximize profits for a durable good in a competitive environment are examined. Quality will be divided into two components a moc

Q1)

w

made

adver

develo

the in

explic

of the

comp

with c

herein

compe

zero r

impac

Once

compe

compe

impact

for one

continuous quality improvement component and a discontinuous quality component. The model developed is expected to be able to address several questions.

Q1) What are the optimal price trajectory and optimal advertising level trajectories when they are impacted by quality and interact with each other in a duopoly?

In its original form the NGM model (Narasimhan et al. 1993) and the modifications made to it in 1996 (Narasimhan et al. 1996) did not explicitly incorporate competition or advertising. As such it is possible to make extensions to the literature from the model developed in this dissertation by considering competition explicitly. It is to be expected that the impact quality has on the optimal price trajectory will be different when competition is explicitly considered than when it is implicit. By adjusting advertising levels to zero the impact of the optimal price trajectories in a duopoly may be considered and used as a baseline for comparison with results when competition is not explicit. Advertising impact in conjunction with quality trajectories has not been considered in the literature and an extension is made herein.

The impact of advertising may be considered in this model independently of the competitive environment. Setting the market potential of one of the two competitors equal to zero removes it from the game and allows for an investigation into how advertising might impact a firm without the competitor. This will establish a baseline for advertising effects. Once this baseline is established for comparison purposes the market potential for the competitor which was set to zero is reestablished and allowed to vary as is the first competitor's. The next set of simulation runs made in the first set of scenarios examines what impact advertising has when only one competitor engages in advertising. The advertising level for one competitor is set to a non-zero level and the level for the second is set to zero. This has a

state

Scena

with t

length

decisi

Q2) I
ex

comp

1. Th

levels

be ef

differ

It is e

terms

the qu

allows an examination of the diffusion component alone when compared with advertising and diffusion. See Scenario 1.2 Table 1. A comparison of two different advertising rates when the two competitors have equal quality trajectories is made in Scenario 1.3. See Scenario 1.3 Table 1. The last scenario in the first set is intended to examine what happens when one competitor has an increasing quality trajectory and low levels of advertising when compared with a stead-state quality position and high levels of advertising. This is examined in Scenario 1.4. See Scenario 1.4 Table 1. Each of the investigations is made with two different elasticity values and with two different product lifetimes. The investigations are also considered using two different lengths of time during which the quality of the product continues to influences purchasers' decisions, in particular 0.25 and 0.75 the total life expectancy of the product.

Q2) How do differences in a firm's quality policy interact with its advertising expenditures to influence the optimal price trajectory to maximize profit?

A baseline is established for comparison by setting the advertising levels for both competitors to zero and both quality trajectories equal to each other. See Scenario 2.0 Table 1. The next two scenario groups set the advertising for the first competitor to two different levels, 1.7% of revenues and 3.5% of revenues. With the base line established advertising will be effects will be reintroduced to the model. The quality trajectories will be varied so that different quality strategies may be compared when they are influenced by advertising policies. It is expected that advertising will provide assistance to firms incorporating quality changes in terms of their short term sales but that it will not provide a substantial increase in sales once the quality has begun to diffuse into the market.

repr

One

firms

chang

See S

prod

adve

exam

profi

Neit

mod

com

their

com

qua

envi

into

Q3) How do advertising policies interact with discontinuous product quality characteristics over time? Will one balance the other or does the influence of one or the other become more important as time progresses?

The third scenario introduces a discontinuous quality change. This type of change is representative of the introduction of a radical process or model change to a durable product. One competitor in the model will have a discontinuous change in its quality trajectory. Both firms will have equal advertising. In the next scenarios advertising for the competitors will change from one firm to the other to consider the impact advertising has in this environment. See Scenario 3 Table 1.

Summarizing, the interaction of advertising and quality on the profit generated by a product line over its life will be investigated in this dissertation by considering the impact of advertising, varying quality strategies and the combination of the two. The NGM model examined how a continuous quality improvement policy impacts a product's lifelong profitability, however the potentially mitigating factor of advertising was not addressed. Neither did the original NGM model explicitly consider competition. Various advertising models have examined how sales may be influence by advertising. This has been done in competitive environments but these investigations have not considered quality trajectories in their analysis. By combining differing advertising efforts for different quality profiles for two competing companies it becomes possible to investigate what the interactions advertising and quality have on the optimal price trajectories over the life of a durable good in a competitive environment. The consideration of these interactions in this dissertation extends the literature into heretofore unaddressed areas. A summary of the simulation factors is given in Table 1.

SCENARIO DEVELOPMENT				
	Advertising	Market	Advertising	Advertising

SCENARIO DEVELOPMENT								
$T=2D_1$	Price	Quality Trajectories	Delay constants D1,D2		Advertising levels	Market Penetration	Advertising elasticity	Advertising decay
	P_1,P_2	Q_1,q_2	Comp 1	Comp 2	A_1,A_2	β_1, β_2	α_1,α_2	δ
Scenario 1.0	Free	Continuous & = 0.5-0.6	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=A_2=0$	$\beta_1=\beta_2=0$	Zero to a power	Zero
Scenario 1.1	P_2 = None	$q_1=0.5$ to 0.6 q_2 None	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=1.7\%R_1$ A_2=None	$\beta_1=0.5$ β_2= None	$\alpha_1=0.05$ α_2 = none	$\delta=0.5$
Scenario 1.2	Free	$q_1=0.5$ to 0.6 $q_2=0.5$ to 0.6	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=3.5\%R_1$ $A_2=1.7\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$
Scenario 1.3	Free	$q_1=0.5$ to 0.6 $q_2=0.5$ to 0.6	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=3.5\%R_1$ $A_2=1.7\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$
Scenario 1.4	Free	$q_1=0.6$ to 0.9 $q_2=0.75$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=1.7\%R_1$ $A_2=3.5\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$
Scenario 2.0	Free	$q_1=0.5$ to 0.6 $q_2=0.5$ to 0.6	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=A_2=0$	$\beta_1=\beta_2=0$	Zero	Zero
Scenario 2.1	Free	$q_1=0.35$ to 0.75 $q_2=0.5$ to 0.6	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=A_2=0$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$
Scenario 2.2	Free	$q_1=0.35$ to 0.75 $q_2=0.5$ to 0.6	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=3.5\%R_1$ $A_2=0\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$
Scenario 2.3	Free	$q_1=0.5$ to 0.9 $q_2=0.5$ to 0.6	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=0\%R_1$ $A_2=0\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$
Scenario 2.4	Free	$q_1=0.5$ to 0.9 $q_2=0.5$ to 0.6	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=0\%R_1$ $A_2=3.5\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$

Table 1- Scenario Development

SCENARIO DEVELOPMENT								
$T=2D_1$	Price	Quality Trajectories	Delay constants D1,D2	Advertising levels	Market Penetration	Advertising elasticity	Advertising decay	
	P_1,P_2	q_1,q_2	Comp 1	Comp 2	A_1,A_2	β_1, β_2	α_1,α_2	δ
Scenario 3.0	Free		$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=0\%R_1$ $A_2=0\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$
Scenario 3.1	Free		$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=1.7\%R_1$ $A_2=3.5\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$
Scenario 3.2	Free		$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=1.7\%R_1$ $A_2=1.7\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$
Scenario 3.3	Free		$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=1.7\%R_1$ $A_2=3.5\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$
Scenario 3.4	Free		$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=1.7\%R_1$ $A_2=1.7\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$
Scenario 3.5	Free		$D_1=3,10$ $D_2=.25D_1,.75D_1$	$D_1=3,10$ $D_2=.25D_1,.75D_1$	$A_1=1.7\%R_1$ $A_2=1.7\%R_2$	$\beta_1=\beta_2=0.5$	$\alpha_1=\alpha_2=0.05$	$\delta=0.5$

Table 1 (cont'd)

adve

quai

uses

been

profi

cond

show

policy

also i

Gam

firm

attem

is no

comp

existe

with

Super

CHAPTER 2

Literature Review

The literature that supports this dissertation includes information on dynamic games, advertising models, advertising models that include competition, the impact that product quality has on sales and literature that examines disaggregated quality. Since this dissertation uses an optimal control methodology the emphasis in searching for literature information has been placed on models that use optimal control methodology to investigate how a firm's profits might be maximized given environmental conditions and the firm responses to those conditions. The most salient information to this work has been taken from literature that shows how interactions between advertising, product quality, competition and product pricing policy impact the profitability of a firm. General information on the framing of the problem is also included in the following literature summaries.

Game Theory/Optimal Control Models

Competition between firms may be viewed as an effort to gain levels of sales by one firm that maximizes its profitability while other firms competing in the same market are attempting to maximize their own payoffs. It should be noted here that one firm or the other is not attempting to "beat" the competition in the sense that a victory implies the end of the competition but rather that they are attempting to maximize their own returns. The continued existence of the competition is not necessarily relevant to maximized profits. This is consistent with the class of games identified as Strategic-Form Games by Fudenberg and Tirole (1996). Super imposed on this competition are limiting factors. The most significant of these is the inf

and

gam

actio

discr

solut

optim

Adve

impro

jointl

Vidal

policy

not in

the pr

pricing

advert

depict

lack of perfect information available to the competing firms. This limitation on information takes two forms, first is the lack of information pertaining to the conduct of consumers and second is the lack of information relative to the actions of the completion. This lack of information pertains only to future events. The entire set of activities for both the competition and consumers leading up to the present point in time is available to all parties. These types of games are classified by Fudenbers and Tirole (1996), as "multi-stage games with observed actions." Time in this classification of strategic games is treated as a series of separate and discrete units or states. Optimal solutions for this type of game take two forms, an open loop solution and a closed loop solution. This dissertation will use an open loop form of the optimal control solution.

Advertising Literature

Models that examine how companies use various promotion or advertising policies to improve sales response have a long history. Dorfman and Steiner (1954) developed a model to jointly examine optimal advertising expenditures while jointly optimizing pricing and quality. Vidale and Wolfe, (1957) developed a model that demonstrated the most efficient advertising policy a company could use to maximize its sales, and therefore its profits. The 1957 work did not include competition explicitly. Vidale and Wolfe did not incorporate the quality aspects of the product as a factor in creating sales. Nor did they consider the possible impact a dynamic pricing policy might have on sales. A graphical representation of the sales response to advertising as depicted by the Vidale-Wolfe model is shown in Figure 3. The sales response is depicted by s(t), the total market potential is depicted by m, the advertising pulse is on until time τ and the saturation sales response or the maximum sales that may be generated by infinite advertising expenditures, is shown as r(x).

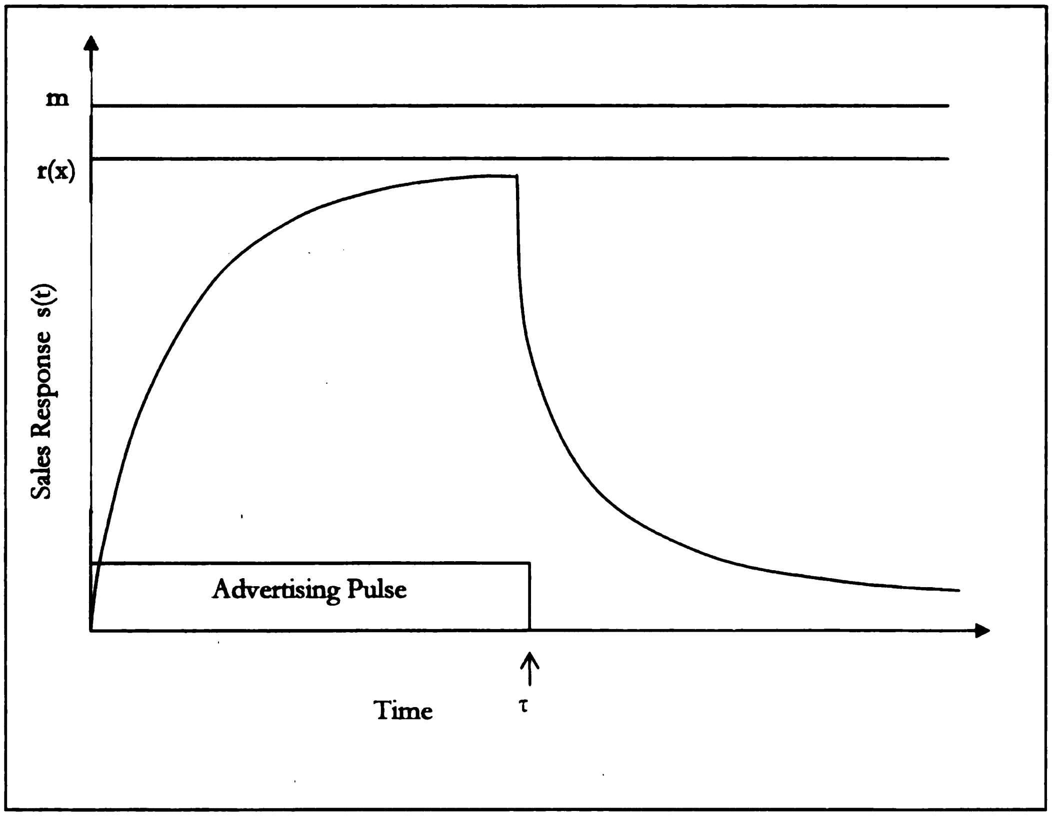


Figure 3 – Vidals-Wolfe Sales Response

Little (1979) summarized the state of the art as of that date in aggregate advertising models. In his summary, he identified five basic principals that a dynamic advertising model should incorporate. First, that the sales response should change upward or downward in response to differing levels of advertising expenditure and that these changes may occur at different rates. Second, he asserts that the steady-state sales response should be either S-shaped

req
resp
due

adve
whic
Mah
polic
polic
pulsi
1992
expe
are
deve
only
beco
(199
max
Wol
ever

pres

or concave. Also, those sales levels at zero advertising might not be zero. Little's third requirement for an advertising model is that it includes the influence of competition in its sales response. Fourth, advertising effectiveness can change over time and fifth that sales increases due to adverting falls off or decays over time.

Great attention has been paid to considering the optimal pattern of expenditures for advertising. In particular two researchers (Lilien et al. 1992; Mahajan and Muller 1986) examine which advertising policies give the most effective sales response to advertising expenditures. Mahajan and Muller (1986) identify five possible policies for advertising expenditures. The policies are: the Blitz policy, the Pulsing policy, the Chattering or Flighting policy, the Even policy and the Pulse/Maintain policy. Several authors have since examined advertising when a pulsing policy is used. Using several models including the Vidale-Wolfe model, (Feinberg 1992) examined the chattering policy, the pulsing policy and the even policy of advertising expenditures. Feinberg concludes that in general neither the chattering nor the even policies are optimal and that the optimal policy might be the pulsing policy. Naik et el (1998), developed a model suggesting that the pulsing strategy was superior to an even strategy but only because of a wearing out of the advertisement, by which they mean the consumers become board with the advertisement. Assuming that pulsing policies are adopted Villas-Boas (1993) showed that advertising pulses of competing firms should be out of phase in order to maximize profits. Using a dynamic programming approach and a modification of the Vidale-Wolfe model Mesak et el. (2001) showed that a pulsing policy dominated the continuous or even advertising strategy.

Models have been developed that consider advertising expenditures without prescribing the pattern of the advertising expenditures (Fruchter 1999; Fruchter and Kalish p

sale

disc

spen

auth

sales

and

gener

Vidal

(199

duop

Erick

as

inco

proc

diffe

beer

to m

pric

qual

1997; Fruchter and Kalish 1998). Models that do predetermine the advertising patterns, e.g. pulse vs. even are not limited by having an exogenous spending pattern superimposed on the sales response function. Not using a predetermined pulsing pattern also eliminates t discontinuities that are generated when response functions are converted from an advertising spending period to a non-spending period. It is important to note here that none of the authors examining advertising pulsation polices have considered quality as a factor impacting sales.

Optimal control modeling has been used to examine the relationship between sales and advertising several times. Sethi (1973; 1974; 2000) examined the maximum sales revenue generated by optimizing advertising expenditures. In all three cases a modified version of the Vidale-Wolfe model was used as a basis for developing the optimal control model. Erickson (1991) modified the Vidale-Wolfe model and used the result to analyze market sales in a duopoly. He considered both the open and closed loop forms of this analytical model. Erickson (1985; 1997) has also examined applying the Lanchester model to advertising as well as the Vidale-Wolfe model. None of these investigations into advertising strategies incorporated the product quality as a factor influencing sale. Since the specific aspects of the product were not considered it may be surmised that the products under consideration are not differentiable by the consumer. Two summaries of optimal control models in advertising have been published (Feichtinger et al. 1994; Sethi 1977).

Bass (1969) introduced a diffusion model that determined the optimal price trajectory to maximize corporate profits realized over the life of a product. This model included dynamic pricing as a strategic tool for increasing sales but it neither incorporated competition nor quality as factors impacting sales nor did it incorporate the effect advertising had on the

Bas

rese

imp

Adv

deve

expe

adve

curve

"Wor

addit

adver

mode

dynar

consi

good

optimal price trajectory. Mahajan, Muller and Bass (1990) reviewed the state of the art of new product diffusion models and noted that there was a need for models that incorporated product i.e. quality, aspects into diffusion models. Krishnan, Bass and Jain (1999) refined the Bass model and specifically called for the incorporation of competition into diffusion model research. While addressing quality and competition these authors did not incorporate the impact of advertising explicitly into their model.

Advertising Literature Including Competition

Several authors have incorporated competition into advertising models. Deal (1979) developed an extension to the Vidale-Wolfe model to consider optimal advertising expenditures in a dynamic duopoly. Teng and Thompson (1983) developed a model of advertising in an oligopoly and included the production costs when they obeyed a learning curve. Jones (1983) developed a dynamic model of advertising in a duopoly and considered "Word of Mouth" or the contribution that the diffusion of information makes to sales in addition to the advertising pursued by the company. Horsky and Simon (1983) considered advertising as it applied to the diffusion of new products. Erickson (1991) used diffusion models to examine sales and advertising relationships. Sorger (1989) addressed competitive dynamic advertising as a Nash equilibria differential game. Chintagunta and Vilcassim (1992) considered advertising strategies in a dynamic duopoly using empirical data for non-durable goods.

Quality

Quality has been associated with operations strategy as a means of gaining a competitive edge for many years (Phillips et al. 1983; Swamidas 1986; Teece 1985). Extensive research on quality and the impact quality has on profitability has been conducted. However, this work has centered on conformance to specifications as a measure of quality (Fine 1986; Garvin 1983). For a comprehensive treatment of quality as conformance to specification see. (Garvin 1988; Juran and Jr. 1980; Montgomery 1985). There has also been some treatment of quality in other contexts than conformance. Garvin (1988) identifies eight different facets of quality that may be associated with product quality of these four, performance, features, durability and reliability, are easily associated with design or engineering quality. Many of these are interrelated. The quality of a product has been tied to both advertising and price as a means of enhancing sales.

Dorfman and Steiner (1954) demonstrated that there exists an optimal level of advertising that should be associated with any given level of product quality at a market price. The implication of their work is that excessive advertising for a product given a level of quality is that profits are reduced because of the unproductive advertising. Similarly insufficient levels of advertising results in too low a sales rate and again profits are not maximized. Dorfman and Steiner did not examine an explicitly competitive environment but rather adjusted the price, advertising and quality level of the modeled product to exploit different consumers with differing price and quality requirements.

Quality and its relationship with price as a signal of quality has been examined for many years. Scitovsky (1945) connected quality with consumer behavior by establishing the idea that in the absence of other information rational consumers evaluate quality levels with product price. The relationship between pricing and quality was further investigated and confirmed by Leavitt (1954). More recently this relationship has been questioned. Several researchers (Gerstner 1985; Riesz 1978; Riesz 1979; Sprokes 1977) have all found that that the ability of price to signal quality to the consumer is weak at best. In an effort to clarify the quality-price relationship Lichtenstein and Burton (1989) examined the relationship pertaining to both durable and non-durable goods. Rao and Monroe (1989) found a positive and statistically significant relationship between price and quality as it is perceived by the consumer. El Ouardighi and Tapiero (1998) examine price as a signal of quality in an environment where demand is more sensitive to quality as new innovations for a product diffuse into the market place.

Many treatments of product diffusion into a market place where quality is held constant have been examined (Dolan and Jeuland 1981; Horsky 1990; Horsky 1977; Horsky and Mate 1988; Horsky and Simon 1983; Kalish 1985; Mahajan et al. 1984; Muller 1983). While informative this is less beneficial than considering a changing or dynamic quality profile. The changes in quality that are brought about either continuously, as is the case when applying a learning curve to production, or discontinuously as when companies design new features and add them to a product need to be factored into managerial decisions..

Narasimhan, Ghosh and Mendez (1993) developed the NGM model to demonstrate how quality impacts the evolution of the sales of a durable good over its life with evolving quality levels. This was the first diffusion model that explicitly incorporated the changing attributes of a product, its quality. In a subsequent paper Narasimhan, Ghosh and Mendez (1996) used the NGM model to develop an optimal pricing strategy to maximize profits for a dur

sev

and

20

for

(Me

the

prov

diss

Qua

exter

little

qual

but

cons

durable good during its life cycle. The NGM model has been referenced when considering several aspects of quality, including customer loyalty factors, the speed of quality improvement and strategic factors (Devaraj et al. 2001; Foster and Adam 1996; Narasimhan and Mendez 2001). The NGM model has been considered when examining advertising diffusion models for new products and diffusion models considering incorporating replacement purchases (Mesak and Berg 1995; Mesak and Clark 1998). The NGM model has even been referenced in the development of a smoking cessation study (Mendez et al. 1998). The NGM model provides a base to develop the quality and diffusion components of the dynamic model this dissertation.

Quality including Competition

While optimal control models examining advertising in conjunction have received extensive attention (see above). Quality in a competitive environment has receives surprisingly little attention. Kourelis and Mkhopadhyay (1995) examine competition when considering quality as a strategic factor in the market. They use quality and price as optimal control variable but do not consider advertising as a modifier to their model. Luptacik and Mikulas (1982) consider quality, advertising in the specialized case of atomistic competition.

Disaggregated Quality

Nelson (1970) introduced the concept that consumers deal with two types of quality in products. The terms he applied are search goods and experience goods. He identified search goods as those goods that consumers can determine relative quality levels via inspection. In other words, a consumer may examine a product before purchasing and determine whether or not it has a higher level of quality than its competition. Alternatively the experience good is one that the consumer must purchase and use before they are able to establish quality levels. This distinction of the types of quality is directly applicable to individual durable goods. There exist two types of quality in a durable good that may be established by inspection, the fit and finish of an automobile for example and its engineering quality the durability or performance ability of its components or systems. The concept of search quality and experience quality was examined again by Nelson (1974) and has also been examined by several other researchers (Milgrom and Roberts 1987; Milgrom and Roberts 1986a; Milgrom and Roberts 1986b; Shapiro 1982; Shapiro 1983). Another interesting point that Nelson (1970) makes about two types of quality is that consumers will collect information from friends and family members before they begin a trial and error process of experience.

Garvin (1988) identifies eight factors that represent quality aspects of a product. Of the eight attributes, performance, features, durability and reliability are factors that must be designed into the product and cannot simple be improved by learning how to build the product more efficiently. The other factors improve with practice or by learning. It is possible for improvements in quality to be achieved by methods other than by learning. These have been termed revolutions or paradigm shifts by Reisman (1992). These paradigm shifts are also ret

cor

[R

fol

rep

incr

mad

Pot

dvd

ons

tran

f b

ie e

flud

rac

ph

sp

an

no

referred to as breakthrough improvements associated with the reengineering process and are commonly taught to undergraduates as strategies for reducing process costs. See for example (Russell and Taylor 2003). The results of a paradigm shift or discontinuity in quality are two fold. First the increase in quality should increase the number of consumers positively representing the product to other consumers engaged in collecting information, thereby increasing the level of sales. Second is the reduction in cost that a firm realizes after having made a paradigm shift.

Potential Contributions to the Literature

There are three areas where the literature may be extended by this work. Generally, advertising models that examine sales response to advertising levels do not specifically consider the impact of quality as a factor influencing sales. Advertising models such as the Brandaid (Little 1979) model, might be argued to indirectly incorporate quality as a component of brand recognition, however quality is not examined explicitly. This is interesting in light of the established importance of product quality to purchasing decisions.

The second area in the literature that warrants more attention is how competition influences the diffusion of quality weighted goods into the market place. Few if any practitioners exist in a monopolistic environment. Models that do not incorporate competition explicitly when examining quality diffusion are not able to examine questions of effective responses to a competitor's quality strategy, and the most opportune time to implement changes in strategic quality policies. Optimal pricing policies that are suggested by models that do not incorporate competition have limited application in a competitive environment.

The third potential expansion of the literature is that most models only consider continuous quality improvements. These models do not allow for the radical change in the quality of a product that is accompanied by a breakthrough process improvement or engineering change in the product. The capability of considering this type of change is important because many durable goods, such as automobiles, experience such changes during their product lifetime. These changes impact the ability of the firm to charge a higher price for the improved product or at least to realize improved revenue. In fact if the firm is to recover the costs of such a change it is necessary for the firm to demand a higher price for products that have undergone such changes or to increase their revenue stream. Table 2 shows the areas where emphasis has been placed to date on advertising, competition and quality models. Notable, is the lack of attention Quality has received.

This dissertation will address some of the areas in the literature that have not been well addressed. It will consider quality in two ways which has not been done. First, it will incorporate quality as a continuously improving function. Second, it will consider discontinuous or breakthrough quality improvements, those types of quality improvements that occur in large increments. This dissertation will also consider the combination of advertising and quality as factors influencing sales. This dissertation will also consider these factors in a competitive environment, more specifically in a duopoly. While some of these factors and how they influence sales have been examined individually the combination has not been combined into a single model before this time. This combination will allow for insights into how managers can most efficiently shift resources to focus on those factors that provide the most return as time progresses.

CITATION	ADVERTISING	COMPETITION	QUALITY	DISAGGREGATED QUALITY
Balachander, S. and K. Srinivasan (1994)			*	
Bass, F. M. (1969)	*			
Chintagunta, Pradeep K. and Naufel J. Vilcassim (1992)	*	*		
Deal, Kenneth R. (1979)	*	*		
Devaraj, S., K. F. Matta, and E. Conlon (2001)			*	
Dorfman, R. and Steiner, P.O. (1954)	*		*	
Erickson, Gary M. (1991)	*	*		
Erickson, Gary M. (1985)	*	*		
Erickson, Gary M. (1997)	*	*		
Feichtinger, G., R. F. Hartl, and S. P. Sethi (1994)	*	*		
Feigenbaum, Armand V. (1983)			*	
Feinberg, Fred M. (1992)	*	*		

Table 2– Literature Summary

CITATION	ADVERTISING	COMPETITION	QUALITY	DISAGGREGATED QUALITY
Foster, S. T. and E. E. Adam (1996)			*	
Fruchter, G. E. (1999)	*	*		
Kouvelis, P., Mukhopadhya, S.K(1995		*	*	
Luptacik Mikulas (1982)	*	*	*	
Narasimhan, R. and D. Mendez (2001)			*	
Narasimhan, Ram, Soumen Ghosh, and David Mendez (1993)			*	
Narasimhan, Ram, David Mendez, and Soumen Ghosh (1996)			*	
Nelson, P (1970)				*
Nelson, P (1974)				*
Rao, Akshay R. and Kent B. Monroe (1989)			*	

Table 2 (cont'd)

C
Sc
Sc
Sc
Sc P.
Fr Ka
Fru S Ka
Ho and Sim
Jon C
K T F F Dip
Li I Ko

CITATION	ADVERTISING	COMPETITION	QUALITY	DISAGGREGATED QUALITY
Sethi, Suresh P. (1977)	*	*		
Sethi, Suresh P. (1973)	*			
Sethi, Suresh P. (1974)	*			
Sethi, Suresh P. and Gerald L. (2000)	*	*		
Fruchter, G. E. and S. Kalish (1998)		*		
Fruchter, Gila E. and Sholomo Kalish (1997)	*	*		
Horsky, Dan and Leonard S Simon(1983).	*	*		
Jones, Phillip C. (1983)	*	*		
Krishnan, Trichy V., Frank M. Bass, and Dipak C. Jain (1999)		*		
Lilien, Gary L., Philip Kotler, and K. Sridhar Moorthy (1992)	*	*		

Table 2 (cont'd)

CITATION	ADVERTISING	COMPETITION	QUALITY	DISAGGREGATED QUALITY
Little, John D. C. (1979)	*	*		
Mahajan, Vijay and Eitan Muller (1986)	*	*		
Mahajan, Vijay, Eitan Muller, and Frank M. Bass (1990)	*	*		
Mesak, H. I. and W. D. Berg (1995)	*	*	*	
Mesak, H. I. and J. W. Clark (1998)	*		*	
Mesak, H.I. and H. Zhang (2001)	*	*		
Naik, Prasad A., Murali K. Mantrala, and Alan G. Sawyer (1998)	*	*		

Table 2 (cont'd)

CHAPTER 3

Model Development

This dissertation will develop a dynamic model that will incorporate price, quality and advertising expenditures for two competing durable goods as inputs and will generate sales levels and thereby profits as outputs. It will optimize the price trajectory and the advertising expenditures to maximize profits. Figure 2 shows a schematic view of the proposed model. The model will be developed using the NGM model, (Narasimhan et al. 1993) as a basis to determine the diffusion sales of quality weighted goods into the market and how that influences the optimal price trajectory. This dissertation and will incorporate advertising components from the Vidale-Wolfe model (Vidale and Wolfe 1957) and from Erickson's (1985) advertising competition model as the basis for advertising's contribution to sales. The model will be bounded by the fact that products have a life cycle. That is, they have a point at which products are introduced and they have a point at which they are withdrawn from the market. This period will be twenty years. Tests of the model for forty years will establish that there are no abnormalities associated with the twenty year time span.

The NGM Model

The objective of the NGM model is to maximize the total discounted profits at a terminal time T it uses price as the optimal control function. The profit function is:

(3.0.1) $$\Pi_t = \int_o^T (P_t - C_t) * S_t * e^{-(rt)} dt$$

Where:

P
(
S
r
Th
(3.
(3.
(3.
(3.
(3.
(3
W
M
Pr
M
Q
S(
Y(
X(
con
EQ
q(t)=
D.=
D.=
a= p
ε= p
relat

P_t = the price at time t
C_t = the cost at time t
S_t = the sales at time t
r = the discount rate.

The remainder of the NGM model is specified as follows:

(3.0.2) $$M(P) = \left[\frac{P_0}{P}\right]^{\epsilon} M_0$$

(3.0.3) $$Q(t) = D_1 * Y(t)$$

(3.0.4) $$\dot{E}Q(t) = D_2 * X(t)$$

(3.0.5) $$S(t) = \alpha * EQ(t) * (M(t) - Q(t))$$

(3.0.6) $$\frac{\partial Y(t)}{\partial t} = \frac{1}{D_1}(S(t) - Y(t))$$

(3.0.7) $$\frac{\partial X(t)}{\partial t} = \frac{1}{D_2} * \left((q(t) * S(t) - X(t))\right)$$

Where:

M_0 = Initial market potential
P(t)= Price in dollars
M(P)= Market Potential in units
Q(t)= # of units in the market in units
S(t)= Sales rate in units/time
Y(t)= Rate at which units leave market in units/time
X(t)= Rate at which quality weighted quantity of goods in the market ceases to influence consumers' buying in units/time
EQ(t)=Quality weighted quantity of goods in the market in units
q(t)=Quality index at time t, q(t)$\in$ (0$\rightarrow$1)
D_1= Average life of the unit in time
D_2= Average time of the effect of quality of goods on consumer's buying behavior
α= Proportionality constant used to calculate sales rate in reciprocal times*units
ϵ= Price elasticity characterizing how sensitive the market potential is for the specific product relative to price.

Typical price trajectories for the NGM model are shown in Figure 4. Note that the

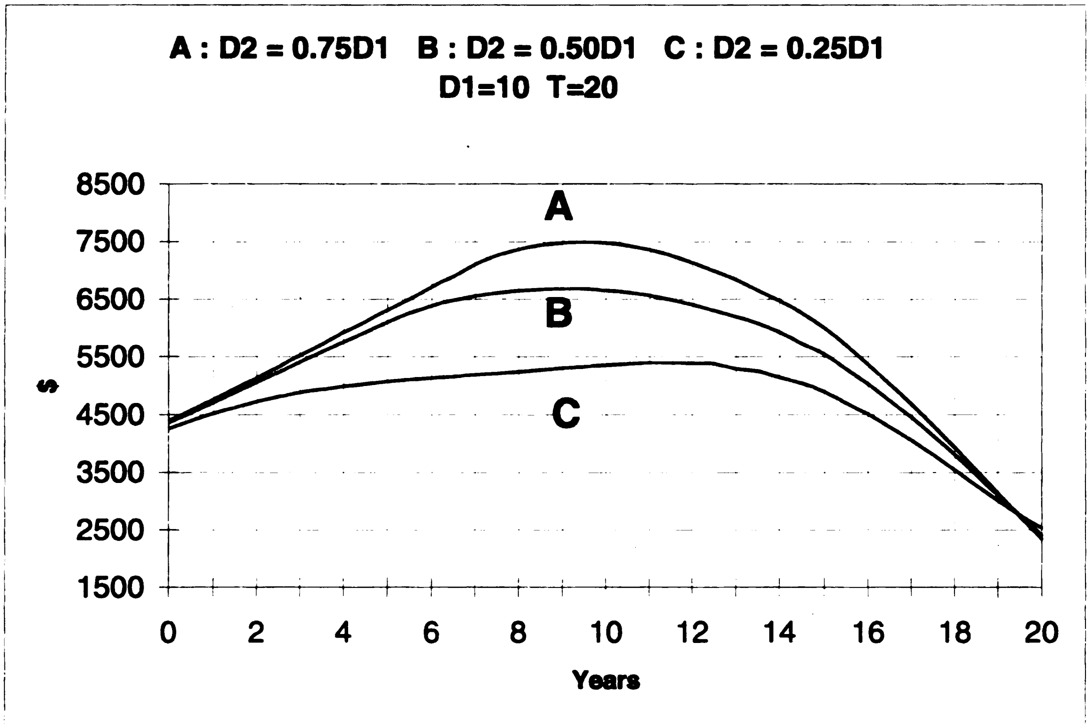


Figure 4 Typical NGM Price Trajectories

price increases before it declines to a final value lower than the initial price point.

This dissertation will retain the NGM objective of maximizing profits generated by a durable good over its life expectancy. The NGM model will be modified to allow for advertising and explicit competition. In order to achieve these ends modifications will be made in several stages. The first modification is the inclusion of advertising into the NGM model.

Advertising

The advertising component is developed first from the Vidale-Wolfe model (Vidale and Wolfe 1957). In the original monopolistic model the change in sale rate is:

(3.1.1) $$\frac{ds}{dt} = \rho x[1-(s/m)] - \lambda s$$

Where:

ρ = a response constant (sales units/\$/period)
s = sales
m = saturation sales rate (sales units/period)
x = advertising rate (\$/period)
λ = decay constant (period $^{-1}$)

Using empirical data they found that the response to advertising in terms of sales could be divided into two sections if a pulsing advertising policy is followed. This differs if an even policy is followed and this situation will be addressed later. The responses when the advertising is on and off were found to be as follows:

(3.1.2) $$s(t)=\begin{cases} r(x)+[s(0)-r(x)]e^{-[1+(\rho x/\lambda m]\lambda \tau} & 0 \leq t \leq T \\ s(T)e^{-\lambda(\dot{\tau}-T)} & T < t \end{cases}$$

Where:

$r(x) = m(\rho x/\lambda m)/[1+(\rho x/\lambda m)]$
s(0)= steady state sales response sans advertising
s = sales
m = saturation sales rate (sales units/period)
x = advertising rate (\$/period)
λ = decay constant (period $^{-1}$)
T= Time advertising is on
t= total time including time advertising is on and off
ρ = a response constant (sales units/\$/period)

r

W

th

C

di

du

sa

res

m

di

con

to

pre

and

He

loop

dep

Conceptually, m represents the total market potential of the segment in question while r(x) represents the maximum level of sales that can be captured using advertising. The Vidale-Wolfe does not incorporate competition it was developed in a monopoly setting. It is therefore necessary to incorporate competition in the basic Vidale-Wolfe structure.

Competitive Advertising

Vidale and Wolfe (1957) demonstrated that advertising expenditures have a diminishing affect on the level of sales over time. They also showed that the increase in sales due to advertising continues after the active advertising is discontinued, but that the resultant sales from advertising decays from the point in time when the advertising ceases. This response is represented in Figure 2.

An important point should be noted from this representation of the Vidale-Wolfe model. The fall-off in sales is represented as instantaneous once the advertising is discontinued. This discontinuity is not realistic in that some time must elapse before consumers begin to "forget" an advertising campaign. The Vidale-Wolfe model was intended to capture the level of sales created by advertising above a minimum level of sales. Those present without any advertising at all. Also, the Vidale-Wolfe model is a monopoly response and does not consider competition in the market environment.

Erickson (1991; 1985) modified the Vidale-Wolfe equation to allow for competition. He established the following maximum advertising levels for the two competitors in an open-loop Nash equilibrium. An open-loop Nash equilibrium is one in which the advertising levels depend only on time and not the current state of the system at that time.

(3.2.1) $$\max_{A_1} \int_0^\infty e^{-rt}\left(h_1\left(\frac{\gamma_1}{\gamma_2+\gamma_1}\right)S - A_1\right)dt$$

(3.2.2) $$\max_{A_2} \int_0^\infty e^{-rt}\left(h_1\left(\frac{\gamma_2}{\gamma_2+\gamma_1}\right)S - A_2\right)dt$$

Where:

γ_i = the brand strength of the competitors.

A_i = the advertising of the respective competitor.

h_i = the unit contribution for each competitor to the total sales in the market

s= the total sales into the market.

r = the common discount rate.

These relationships are subject to the following dynamic constraint:

(3.2.3) $$\frac{dS}{dt} = (\beta_1 A_1^{\alpha_1} + \beta_2 A_2^{\alpha_2}) * (N - S) - \delta S$$

Where:

□= the decay rate of current sales.

N = the maximum sales potential e.g. the total market

A_1, A_2= the advertising rate of each competitor respectively.

β_i = the effectiveness of the respective advertising campaign

S = is the sales rate.

α_i = is the elasticity of the advertising for the respective competitor.

(3.2.4) $$\frac{ds}{dt} = N\beta_1 A_1^{\alpha_1} + N\beta_2 A_2^{\alpha_2} - S\beta_1 A_1^{\alpha_1} - S\beta_2 A_2^{\alpha_2} - \delta S$$

This represents the total sales into the market by both competitors. Like the original Vidale-Wolfe model Erickson's adaptation of the Vidale-Wolfe model is only intended to capture sales that exist in the market above the sales generated without any advertising. So the market potential N must be reduced by amount of sales that would be generated by diffusion. Accordingly equation (3.2.4) has been reduced by removing the declining advertising effectiveness δS. Where δ is the rate at which advertising effectiveness declines.

Dockner (1988; 2000) develops an advertising game where the individual cumulative sales for a competitor are:

(3.2.5) $$\frac{dx}{dt} = f^i(p_i, p_j)(N - x_i - x_j), \quad i, j = 1,2 \quad \mathrm{i} \neq \mathrm{j}$$

Or

(3.2.6) $$\frac{dx}{dt} = f^i(p_i, p_j)(N - (x_i + x_j)), \quad i, j = 1,2 \quad \mathrm{i} \neq \mathrm{j}$$

Where:

p_i= price i
p_j= price j
x_i= cumulative sales for i
x_j= cumulative sales for j
N= Total market potential

The total sales into the market are the sum of the sales for competitor i and j. The sales rates $x_i + x_j$ are influenced by saturation and only impact the remaining market potential after the existing sales have been removed from the total market potential. If the sales from the

Erickson extension of the Vidale-Wolfe model are allocated by a function of price in a similar manner sales for the competitors become:

(3.2.7)

$$\left(\frac{ds}{dt}\right)_i = f^i(p_i, p_j)(N\beta_1 A_1^{\alpha_1} + N\beta_2 A_2^{\alpha_2} - S\beta_1 A_1^{\alpha_1} - S\beta_2 A_2^{\alpha_2} - \delta S)$$

The total sales generated needs to have the diffusion component added before allocating the market according to price

(3.2.8)

$$\left(\frac{ds}{dt}\right)_i = f^i(p_i, p_j)[N\beta_1 A_1^{\alpha_1} + N\beta_2 A_2^{\alpha_2} - S\beta_1 A_1^{\alpha_1} - S\beta_2 A_2^{\alpha_2} - \delta S + \alpha * EQ_t * (M_t - Q_t)]$$

Competitive Market Potential

The market potential M_p for the product was modified in the NGM model from the original Bass model by expressing the price-market potential in terms of price elasticity. $M(P_t) = \left(\frac{P_0}{P_t}\right)^e M_0$ where M_0 is the initial market P_0 is the initial price and P_t is the price at time t. The price elasticity, *e*, retains its economic meaning on how sensitive the market is to price changes for the specific product. M_0 is the initial market potential P_0 is the initial price P_t is the price at time t and $M(P_t)$ is the market potential at the price P_t. In order to accommodate the addition of a second product into the market it is necessary to modify this market price relationship. First, the market potential at time zero is restructured so that it is dependant on both initial prices. The market potential at time zero is modified in the following way.

(3.3.1)
$$M_0 = M_{\text{int}}\left[\left(\frac{P_{1,0}}{P_{1,t}}\right)^e + \left(\frac{P_{2,0}}{P_{2,t}}\right)^e\right]$$

In this way M_0 becomes dependent on both initial prices at time zero. $P_{1,0}$ represents the price for product one at time zero. $P_{2,0}$ represents the price for product two at time zero. $P_{1,t}$ is the price of product 1 at time t and $P_{2,t}$, is the price of product 2 at time t. M_{int} represents the initial potential of the market segment at time zero and does not change over time.. The market share for the individual competitor becomes:

(3.3.2)
$$M(P_{i,t}) = \left(1 - \left(\frac{P_{j,t}}{P_{i,t} + P_{j,t}}\right)\right) \quad i, j = 1, 2 \;\; i \neq j$$

Market allocation between the two products may be considered in the following manner. The market share for product one, $M(P_{1,t})$, is:

(3.3.3)
$$M(P_{1,t}) = \left(1 - \left(\frac{P_{1,t}}{P_{1,t} + P_{2,t}}\right)\right)$$

If the price of product one at time t, $P_{1,t}$, approaches infinity then the value 1-$\left(\frac{P_{1,t}}{P_{1,t} + P_{2,t}}\right)$ approaches zero reducing the market share of product one to zero. If the price of product one at time t, $P_{1,t}$, approaches zero then the value 1-$\left(\frac{P_{1,t}}{P_{1,t} + P_{2,t}}\right)$ approaches one and product one's share approaches 100% of the market. If the price of product two at time t, $P_{2,t}$ approaches infinity then the value 1-$\left(\frac{P_{2,t}}{P_{1,t}+P_{2,t}}\right)$ approaches one and product one's market share again approaches 100% of the market. Conversely, if the price of product two at time t, $P_{2,t}$, approaches zero and then the value 1-$\left(\frac{P_{2,t}}{P_{1,t}+P_{2,t}}\right)$ approaches zero and product one's share approaches zero. Similar limiting cases apply to the market share of product two at time t with price $P_{2,t}$.

(3.3.4)
$$\left(\frac{ds}{dt}\right)_i = \left(1-\left(\frac{P_{j,t}}{P_{i,t}+P_{j,t}}\right)\right)*[N\beta_1 A_1^{\alpha_1} + N\beta_2 A_2^{\alpha_2} - S\beta_1 A_1^{\alpha_1} - S\beta_2 A_2^{\alpha_2} - \delta S + \alpha * EQ_t * (M_t - Q_t)]$$

Notice that in the limiting case of no advertising (3.3.4) becomes:

(3.3.5)
$$\left(\frac{ds}{dt}\right)_i = \left(1-\left(\frac{P_{j,t}}{P_{i,t}+P_{j,t}}\right)\right)*[\alpha * EQ(t)*(M(t)-Q(t))]$$

Notice too, that in the case of one firm or the other exiting the market, their price becoming identically equal to zero, (3.3.4), forces the market share for their competitor to one and their market share to zero, no product is available for sale, equation (3.3.4) become equal to the NGM model with no competition. If one competitor exits the market and there is no advertising equation (3.3.4) becomes equal to the original NGM equation. Next the cost relationships for the variable costs of quality and advertising will be addressed.

Costs

The original NGM model (Narasimhan et al. 1993) the cost of the product did not vary with time. The model as modified in 1996 (Narasimhan et al. 1996) used a quality cost that changed over time. Narasimhan et el. (1996) added a cost function that decreased when quality ranged from 0.25 to 0.90 and increased when quality increased from 0.9. to 1.0. In particular they postulated that a plausible representation of the cost of quality would decrease by 40% from 0.25 to 0.90 and increase by 40% from 0.90 to 1.0. They then used a Lagrange interpolation polynomial to generate the unit cost as a function of quality. The result was a forth order polynomial in quality. This was added to a base cost C_0. This relationship was confirmed by interviews with a practitioner. The same cost relationship is applied here to the cost of quality. The variable cost of quality is then added to the fixed production cost. Discontinuous quality increases are added to the production cost as an increase in fixed costs and are incurred in total at the time of the improvement.

The cost of advertising has been modeled in this dissertation as a quadratic function. This is in keeping with Teng and Thompson (1983) and Dockner et al (2000). Specifically the cost relationship used by Teng and Thompson is adopted in this dissertation this is $\delta_i + \beta_i A_i + \alpha_i A_i^2$ where alpha, beta and delta are constants and A_i is the advertising level of the competitor in question. This variable cost of advertising is added to the fixed cost of production and the variable cost of quality improvement giving a total cost at time t of C_t.. This becomes:

(3.4.1) $$C_t = C_{prod} + C_0 + C_1 q_{i,t} + C_2 q_{i,t}^2 + C_3 q_{i,t}^3 + C_4 q_{i,t}^4 + C_5 A_i + C_6 A_i^2$$

Where:

C_i = Constant
A_i = Advertising lever for competitor i
q_{it} = the quality level for competitor i at time t

Quality

The original NGM model and the Bass model both recognize that as products are purchased the market potential for new sales is reduced by the number of units in the market place. However, the Bass model does not reflect the fact that products have a life span and will exit the market. The NGM model does incorporate this fact. The NGM model also reflects the fact that quality will only impact sales for a limited time. Once this time period has been exceeded the quality of existing units in the market place will no longer impact sales.

In addition to the continuous improvement policy established by the NGM model this dissertation will extend that model by adding a discontinuous, or large change, in the quality of the product not present in a continuous or incremental quality improvement program. This reflects the potential for an engineering change in the basic product make-up, such as the introduction of a new process technology to the production of an automobile during its lifetime. The difference in the impact of this change will be reflected in a longer period of time needed for the engineering improvement to impact sales.

The NGM model uses two delay factors, D1, and D2, to capture the amount of time that a product will remain in service and the amount of time that that product will impact sales. It is foreseen that a discontinuous change in quality will be reflected by altering these constants. The length of time that products remain in service D2 is foreseen to increase as the engineering or discontinuous quality improvements begin to diffuse into the market. This

increase in quality should also increase D1, the length of time that a product influences sales in the market. Conversely, if one firm improves its engineering quality and the other firm does not then the length of time that the non-improving company's goods influence sales should decrease and the length of time the product remains in the market should decrease as the market perceives the lower quality levels for the static company.

The Complete Model

The total profits to be maximized for each firm are:

(3.6.1)
$$\Pi_t = \int_0^T (P_t - C_t) * S_t * e^{-(rt)} dt$$

Where:

P_t = the price at time t
C_t = the cost at time t
S_t = the sales rate at time t and
r = the discount rate.

The sales for each competitor is:

(3.6.2)
$$S_{t,i} = \left(1 - \left(\frac{P_{j,t}}{P_{i,t} + P_{j,t}}\right)\right) * [M_0 \beta_1 A_1^{\alpha_1} + M_0 \beta_2 A_2^{\alpha_2} - S\beta_1 A_1^{\alpha_1} - S\beta_2 A_2^{\alpha_2} - \delta S +$$
$$\alpha * EQ_t * (M_t - Q_t)] \quad \text{i,j} \in 1,2 \quad i \neq j$$

The market potential for the entire market at time zero is:

T

(

(3

Th

(3.

Th

(3.

Th

(3.(

The

(3.6.3) $$M_0 = M_{\text{int}} \left[\left(\frac{P_{1,0}}{P_{1,i}} \right)^e + \left(\frac{P_{2,0}}{P_{2,i}} \right)^e \right]$$

The market share for each competitor is:

(3.6.4) $$M(P_{1,t}) = \left(1 - \left(\frac{P_{1,t}}{P_{2,t} + P_{1,t}} \right) \right)$$

(3.6.5) $$M(P_{2,t}) = \left(1 - \left(\frac{P_{2,t}}{P_{2,t} + P_{1,t}} \right) \right)$$

The rate of quality weighted number of units in the market is:

(3.6.6) $$EQ(t) = D_2 * X(t)$$

The number of units in the market at time t is:

(3.6.7) $$Q_t = D_1 * Y(t)$$

The rate at which units leave the market is:

(3.6.8) $$\frac{\partial Y}{\partial t} = \frac{1}{D_1}\left(S(t) - Y(t)\right)$$

The rate at which quality weighted units ceases to influence purchasing decisions.

(3.6.9)

Where:

P(t) =

M(P) =

Q(t) =

S(t) =

Y(t) =

X(t) =

EQ(t) =

q(t) =

D =

$P_{1,0}$ =

$P_{2,0}$ =

$P_{1,t}$ =

$P_{2,t}$ =

δ =

N =

A_i =

β_i =

S =

α_i =

The cost

(3.6.10)

C_i

Where:

C = Const

(3.6.9) $$\frac{\partial X}{\partial t} = \frac{1}{D_2} * \left(q(t) * S(t) - X(t)\right)$$

Where:

P(t) = Price in dollars
M(P) = Market Potential in units
Q(t) = # of units in the market in units
S(t) = Sales rate in units/time
Y(t) = Rate at which units leave market in units/time
X(t) = Rate at which quality weighted quantity of goods in the market ceases to influence consumers' buying in units/time
EQ(t) = Quality weighted quantity of goods in the market in units
q(t) = Quality index at time, $t \in (0 \rightarrow 1)$
D_1 = Average life of the unit in time
$P_{1,0}$ = Price of competitor 1 product at time zero
$P_{2,0}$ = Price of competitor 2 product at time zero
$P_{1,t}$ = Price of competitor 1 product at time t
$P_{2,t}$ = Price of competitor 2 product at time t
δ = the decay rate of current sales.
N = the maximum sales potential e.g. the total market.
A_i = the advertising level of each competitor respectively.
β_i = the effectiveness of the respective advertising campaign
S = is the sales rate.
α_i = is the elasticity of the advertising for the respective competitor

The cost at time t including both quality and advertising is:

(3.6.10)

$$C_t = C_{prod} + C_0 + C_1 q_{i,t} + C_2 q_{i,t}^2 + C_3 q_{i,t}^3 + C_4 q_{i,t}^4 + C_5 A_i + C_6 A_i^2$$

Where:

C_i = Constant

A_i = Advertising lever for competitor i
q_i = the quality level for competitor i at time t

A conceptual diagram of the model is depicted in Figure 4

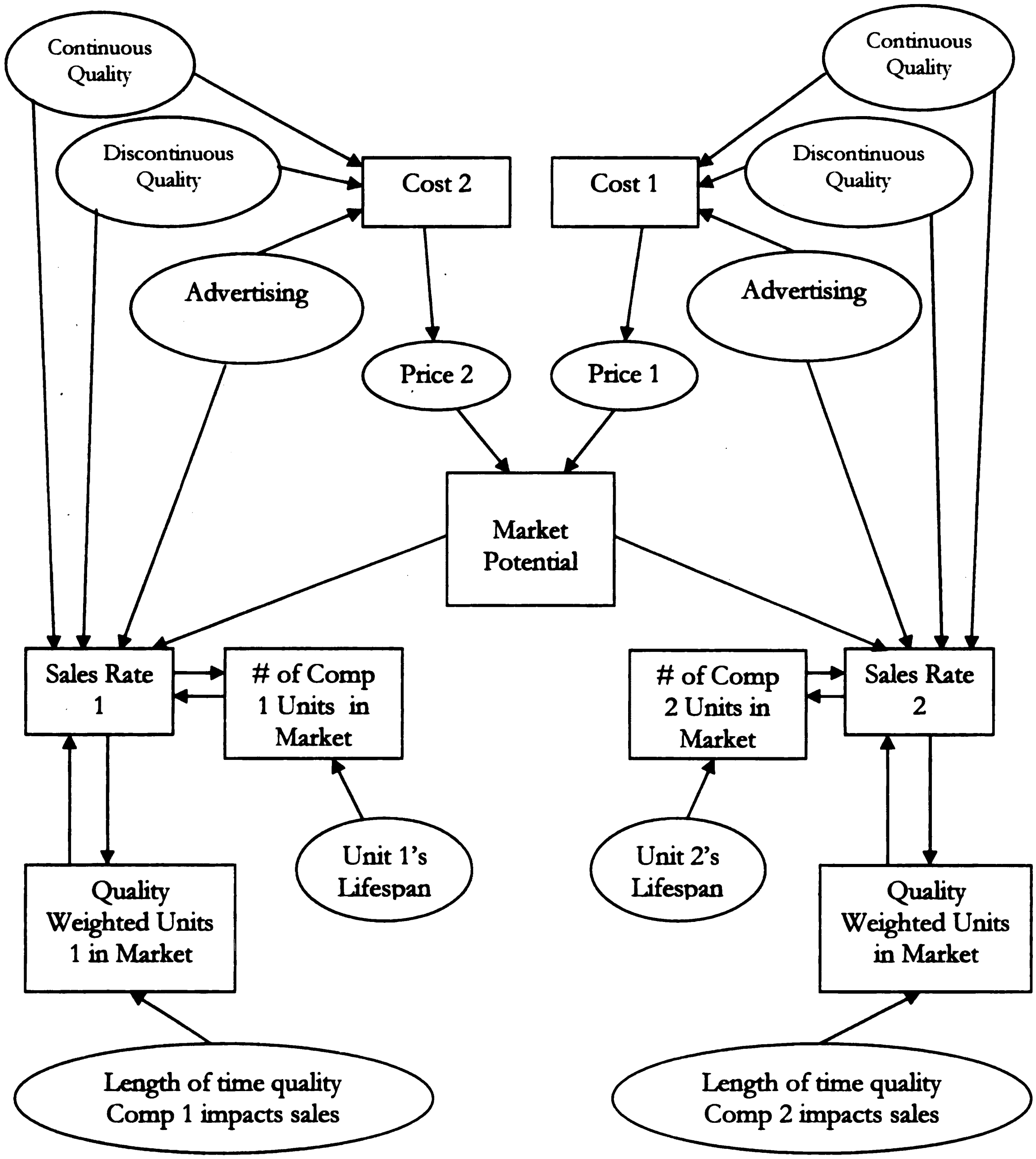


Figure 5-Model Conceptualization

trajec

optim

comp

secon

This i

detern

presen

consta

Thom

term (

values

assum

be hel

into th

1985; l

decays

literatu

Weinbe

Experimental Design

Several scenarios are developed to investigate how, price, advertising levels, and quality trajectories influence the profitability of two competing firms producing durable goods. The optimal price trajectory is determined using the premium version of solver for the first companies' product. Price, market potential, sales and quality information are passed to a second spreadsheet where the optimal price trajectory is determined for the second product. This information is passed to the first sheet where the new price trajectory for the first firm is determined again. This process is continued until no changes in either price trajectory are present.

The model in this dissertation incorporates several parameters that will be treated as constants. There are six cost parameters C_0-C_6 plus the production cost C_{prod}. (Teng and Thompson 1983) used a value of 0.02 for the value of the coefficient on the first order cost term C_5, 0.01 for the value of the second order term C_6 and set the constant term to zero. The values derived in (Narasimhan et al. 1996) are used for the remaining cost constants. It is assumed that each competitor has equivalent cost profiles so the costs for each competitor will be held equal to each other.

Advertising increases the number of sales by increasing the level of product awareness into the portion of the market that has not been taped without the advertising effort (Erickson 1985; Lilien et al. 1992; Little 1979; Vidale and Wolfe 1957). This consumer product awareness decays over time. The decay rate of sales generated from advertising has been examined in the literature, see for example. (Bass and Clarke 1972; Clarke 1976; Clarke 1979; Peles 1979; Weinberg and Weiss 1982) In particular Clarke (1976)estimated that the decay should be approximately 0.62, however Peles(1979) believed this to be too large and Weinberg et el. (Weinberg and Weiss 1982) indicates that the delay should be 0.526. (Erickson 1991) indicates that the range for the decay constant delta is from 0 to 1 and uses 0.5 in his analysis. In keeping with Erickson and approximating Weinberg and Weiss, a value of 0.5 will be used for each of the simulation runs in this dissertation. Each competitor is selling product to the same market segment so the decays will be equal to each other.

Two factors influence advertising sales in this dissertation, the level of advertising effectiveness, β, this is the percentage of untapped customers in the market that the advertising campaign contacts, and advertising elasticity, α, the number of customers that are influenced in their purchase decision as a result of the advertising campaign (Lilien et al. 1992; Little 1979; Vidale and Wolfe 1957). The values for advertising effectiveness, β and advertising elasticity, α are assigned to 0.5 and 0.05 respectively in keeping with the numerical experiments performed by Erickson(1991). It is also reasonable to assume that each competitor has available to it the same ability to develop equivalently effective advertising policies and that the market segment in which they are competing has the same advertising elasticity. Therefore in each of the scenarios these values for each competitor will be equal to each other. Advertising budgets for automotive companies may be found in (Advertisers 1977-2003). Ford motor company spent 1.7% of their sales on advertising. The original NGM model was validated using Ford Mustang data so this is a reasonable figure for an advertising level. When one competitor has a higher level of advertising 3.5% of sales or more then twice the level of advertising of the first competitor is used.

It is necessary to consider different unit lifetimes when considering the total life of a product line. An individual product may be replacement from the same product line after that unit has reached the end of its useful life. To this end Narasimhan et al.(Narasimhan et al. 1996) examined different unit life times or delays before the consumer might consider repurchasing a new unit. They used values for the average life of the product, D_1, and gave them values of 3, 5, and 10 years. Individual units also have a limited period of time during which they influence purchasing decisions by consumers, the quality persistence D_2. In the NGM model this persistence was given values of $0.25D_1$, $0.5D_1$ and $0.75D_1$. The planning horizon, the total life of the product line, T, was set to two levels $0.5D_1$ and $2D_1$ in the NGM model. The demand elasticity; e was set to two values, inelastic 0.7 and elastic 1.3. Thus 36 separate problems were solved. If each of these parameters is used in each of the scenarios the result would exceed 468 problem runs. By reducing D_1, from three time periods to two time periods 3 and 10 years, D_2 from three time periods to two time periods, $0.25D_1$ and $0.75D_1$, keeping e at two values and reducing the planning horizon T to 20 years, the number of solutions is reduced to 120, a manageable number with little loss of generality. Specific description of each set of scenarios follows.

Scenarios 1.0-1.4

Of the five scenarios in scenario group one the first sets advertising to zero for each competitor so that a baseline may be made for the competition sans advertising in a duopoly. The second sets the market potential for the second competitor to zero and the advertising budget for the first competitor to non-zero levels. This is so that a monopoly environment may be considered with the model incorporating advertising. The third scenario has active advertising for the first competitor and no advertising for the second thus giving a comparison of the sales from diffusion combined with advertising and the diffusion sales alone. The fourth scenario

sales ad

compet

second

the first.

that are

quality

details m

scenario has active advertising for each competitor giving insight into the amount of increased sales advertising might contribute. The fifth set of runs that comprise scenario 1.5 has one competitor increase its quality trajectory continuously while advertising at a moderate rate. The second competitor has its quality level remain constant but has a larger advertising rate than the first. This considers whether or not advertising can counter the increased levels of quality that are diffused into the market place over time as more goods are replaced with higher quality ones. The other parameters are held according to the above discussion and specific details may be reviewed in Table 3.

#		COMPETITOR 1							COMPETITOR 2						
	e	D1	D2	A	β	α	δ	q	D1	D2	A	β	α	δ	q
1	0.7	3	.25D1	0.00%	0	0	0	.5-.6	3	.25D1	0.00%	0	0	0	.5-.6
2		3	.75D1	0.00%	0	0	0	.5-.6	3	.75D1	0.00%	0	0	0	.5-.6
3		10	.25D1	0.00%	0	0	0	.5-.6	10	.25D1	0.00%	0	0	0	.5-.6
4		10	.75D1	0.00%	0	0	0	.5-.6	10	.75D1	0.00%	0	0	0	.5-.6
5	1.3	3	.25D1	0.00%	0	0	0	.5-.6	3	.25D1	0.00%	0	0	0	.5-.6
6		3	.75D1	0.00%	0	0	0	.5-.6	3	.75D1	0.00%	0	0	0	.5-.6
7		10	.25D1	0.00%	0	0	0	.5-.6	10	.25D1	0.00%	0	0	0	.5-.6
8		10	.75D1	0.00%	0	0	0	.5-.6	10	.75D1	0.00%	0	0	0	.5-.6
9	0.7	3	.25D1	1.70%	0.5	0.05	0.5	.5-.9	-	-	0.00%	0	0	0	off
10		3	.75D1	1.70%	0.5	0.05	0.5	.5-.9	-	-	0.00%	0	0	0	off
11		10	.25D1	1.70%	0.5	0.05	0.5	.5-.9	-	-	0.00%	0	0	0	off
12		10	.75D1	1.70%	0.5	0.05	0.5	.5-.9	-	-	0.00%	0	0	0	off
13	1.3	3	.25D1	1.70%	0.5	0.05	0.5	.5-.9	-	-	0.00%	0	0	0	off
14		3	.75D1	1.70%	0.5	0.05	0.5	.5-.9	-	-	0.00%	0	0	0	off
15		10	.25D1	1.70%	0.5	0.05	0.5	.5-.9	-	-	0.00%	0	0	0	off
16		10	.75D1	1.70%	0.5	0.05	0.5	.5-.9	-	-	0.00%	0	0	0	off
17	0.7	3	.25D1	3.50%	0.5	0.05	0.5	.5-.6	3	.25D1	0.00%	0	0.05	0.5	.5-.6
18		3	.75D1	3.50%	0.5	0.05	0.5	.5-.6	3	.75D1	0.00%	0	0.05	0.5	.5-.6
19		10	.25D1	3.50%	0.5	0.05	0.5	.5-.6	10	.25D1	0.00%	0	0.05	0.5	.5-.6
20		10	.75D1	3.50%	0.5	0.05	0.5	.5-.6	10	.75D1	0.00%	0	0.05	0.5	.5-.6

Table 3– Scenarios 1 .0 to 1.4

#		COMPETITOR 1							COMPETITOR 2						
	e	D1	D2	A	β	α	δ	q	D1	D2	A	β	α	δ	q
21	1.3	3	.25D1	3.50%	0.5	0.05	0.5	.5-.6	3	.25D1	0.00%	0	0.05	0.5	.5-.6
22		3	.75D1	3.50%	0.5	0.05	0.5	.5-.6	3	.75D1	0.00%	0	0.05	0.5	.5-.6
23		10	.25D1	3.50%	0.5	0.05	0.5	.5-.6	10	.25D1	0.00%	0	0.05	0.5	.5-.6
24		10	.75D1	3.50%	0.5	0.05	0.5	.5-.6	10	.75D1	0.00%	0	0.05	0.5	.5-.6
25	0.7	3	.25D1	3.50%	0.5	0.05	0.5	.5-.6	3	.25D1	1.70%	0.5	0.05	0.5	.5-.6
26		3	.75D1	3.50%	0.5	0.05	0.5	.5-.6	3	.75D1	1.70%	0.5	0.05	0.5	.5-.6
27		10	.25D1	3.50%	0.5	0.05	0.5	.5-.6	10	.25D1	1.70%	0.5	0.05	0.5	.5-.6
28		10	.75D1	3.50%	0.5	0.05	0.5	.5-.6	10	.75D1	1.70%	0.5	0.05	0.5	.5-.6
29	1.3	3	.25D1	3.50%	0.5	0.05	0.5	.5-.6	3	.25D1	1.70%	0.5	0.05	0.5	.5-.6
30		3	.75D1	3.50%	0.5	0.05	0.5	.5-.6	3	.75D1	1.70%	0.5	0.05	0.5	.5-.6
31		10	.25D1	3.50%	0.5	0.05	0.5	.5-.6	10	.25D1	1.70%	0.5	0.05	0.5	.5-.6
32		10	.75D1	3.50%	0.5	0.05	0.5	.5-.6	10	.75D1	1.70%	0.5	0.05	0.5	.5-.6
33	0.7	3	.25D1	1.70%	0.5	0.05	0.5	.6-.9	3	.25D1	3.50%	0.5	0.05	0.5	0.75
34		3	.75D1	1.70%	0.5	0.05	0.5	.6-.9	3	.75D1	3.50%	0.5	0.05	0.5	0.75
35		10	.25D1	1.70%	0.5	0.05	0.5	.6-.9	10	.25D1	3.50%	0.5	0.05	0.5	0.75
36		10	.75D1	1.70%	0.5	0.05	0.5	.6-.9	10	.75D1	3.50%	0.5	0.05	0.5	0.75
37	1.3	3	.25D1	1.70%	0.5	0.05	0.5	.6-.9	3	.25D1	3.50%	0.5	0.05	0.5	0.75
38		3	.75D1	1.70%	0.5	0.05	0.5	.6-.9	3	.75D1	3.50%	0.5	0.05	0.5	0.75
39		10	.25D1	1.70%	0.5	0.05	0.5	.6-.9	10	.25D1	3.50%	0.5	0.05	0.5	0.75
40		10	.75D1	1.70%	0.5	0.05	0.5	.6-.9	10	.75D1	3.50%	0.5	0.05	0.5	0.75

Table 3 (Cont'd)

Scenarios 2.0-2.8

The second set of Scenarios considers the differences between product quality strategies and how advertising influence their results. In the first scenario group, 2.0, the advertising is set to zero and the quality profile for the first competitor is changed from 0.5 to 0.9, the second quality profile is changed from an initial value of 0.5 to 0.6. This establishes a base line for quality changes without the influence of advertising. In the second scenario group 2.1 advertising is held to zero for both firms but the quality for the first company varies from 0.36 to 0.75 while the second varies again from 0.5 to 0.6. This demonstrates how an aggressive quality competitor who starts out behind in the level of quality but improves steadily fairs against a complacent quality competitor who makes no effort to maintain their quality advantage. In the third scenario group, 2.2, the quality trajectories are kept the same for the two competitors but the first adds an aggressive advertising policy on top of the quality changes. In the fourth and fifth scenario groupings different levels of advertising are combined with two quality policies. In all three the quality trajectories are kept the same. Company one improves from 0.5 to 0.9 while the second company only improves from 0.5 to 0.6. The first group in this set, scenario 2.3 adds aggressive advertising to the first competitor and no advertising to the second. The second set has no advertising for either competitor. The third set scenario 2.5 has no advertising for the first competitor but adds aggressive advertising to the second to determine how advertising might mitigate the improvement in the quality of the first competitor. Scenarios 2.6-2.8 show advertising for both firms at two different rates. The other parameters are held according to the above discussion and specific details may be reviewed in Table 4.

#		COMPETITOR 1							COMPETITOR 2						
	e	D1	D2	A	β	α	δ	q	D1	D2	A	β	α	δ	q
1	0.7	3	.25D1	0.00%	0	0	0	.5-.9	3	.25D1	0.00%	0	0	0	.5-.6
2		3	.75D1	0.00%	0	0	0	.5-.9	3	.75D1	0.00%	0	0	0	.5-.6
3		10	.25D1	0.00%	0	0	0	.5-.9	10	.25D1	0.00%	0	0	0	.5-.6
4		10	.75D1	0.00%	0	0	0	.5-.9	10	.75D1	0.00%	0	0	0	.5-.6
5	1.3	3	.25D1	0.00%	0	0	0	.5-.9	3	.25D1	0.00%	0	0	0	.5-.6
6		3	.75D1	0.00%	0	0	0	.5-.9	3	.75D1	0.00%	0	0	0	.5-.6
7		10	.25D1	0.00%	0	0	0	.5-.9	10	.25D1	0.00%	0	0	0	.5-.6
8		10	.75D1	0.00%	0	0	0	.5-.9	10	.75D1	0.00%	0	0	0	.5-.6
9	0.7	3	.25D1	0.00%	0.5	0.05	0.5	.35-.75	3	.25D1	0.00%	0.5	0.05	0.5	.5-.6
10		3	.75D1	0.00%	0.5	0.05	0.5	.35-.75	3	.75D1	0.00%	0.5	0.05	0.5	.5-.6
11		10	.25D1	0.00%	0.5	0.05	0.5	.35-.75	10	.25D1	0.00%	0.5	0.05	0.5	.5-.6
12		10	.75D1	0.00%	0.5	0.05	0.5	.35-.75	10	.75D1	0.00%	0.5	0.05	0.5	.5-.6
13	1.3	3	.25D1	0.00%	0.5	0.05	0.5	.35-.75	3	.25D1	0.00%	0.5	0.05	0.5	.5-.6
14		3	.75D1	0.00%	0.5	0.05	0.5	.35-.75	3	.75D1	0.00%	0.5	0.05	0.5	.5-.6
15		10	.25D1	0.00%	0.5	0.05	0.5	.35-.75	10	.25D1	0.00%	0.5	0.05	0.5	.5-.6
16		10	.75D1	0.00%	0.5	0.05	0.5	.35-.75	10	.75D1	0.00%	0.5	0.05	0.5	.5-.6
17	0.7	3	.25D1	3.50%	0.5	0.05	0.5	.5-.9	3	.25D1	0.00%	0.5	0.05	0.5	.5-.6
26		3	.75D1	3.50%	0.5	0.05	0.5	.5-.9	3	.75D1	0.00%	0.5	0.05	0.5	.5-.6
27		10	.25D1	3.50%	0.5	0.05	0.5	.5-.9	10	.25D1	0.00%	0.5	0.05	0.5	.5-.6
28		10	.75D1	3.50%	0.5	0.05	0.5	.5-.9	10	.75D1	0.00%	0.5	0.05	0.5	.5-.6

Table 4— Scenarios 2 .0 to 2.8

#		COMPETITOR 1							COMPETITOR 2						
	e	D1	D2	A	β	α	δ	q	D1	D2	A	β	α	δ	q
29	1.3	3	.25D1	3.50%	0.5	0.05	0.5	.5-.9	3	.25D1	0.00%	0.5	0.05	0.5	.5-.6
30		3	.75D1	3.50%	0.5	0.05	0.5	.5-.9	3	.75D1	0.00%	0.5	0.05	0.5	.5-.6
31		10	.25D1	3.50%	0.5	0.05	0.5	.5-.9	10	.25D1	0.00%	0.5	0.05	0.5	.5-.6
32		10	.75D1	3.50%	0.5	0.05	0.5	.5-.9	10	.75D1	0.00%	0.5	0.05	0.5	.5-.6
33	0.7	3	.25D1	0.00%	0.5	0.05	0.5	.5-.9	3	.25D1	0.00%	0.5	0.05	0.5	.5-.6
34		3	.75D1	0.00%	0.5	0.05	0.5	.5-.9	3	.75D1	0.00%	0.5	0.05	0.5	.5-.6
35		10	.25D1	0.00%	0.5	0.05	0.5	.5-.9	10	.25D1	0.00%	0.5	0.05	0.5	.5-.6
36		10	.75D1	0.00%	0.5	0.05	0.5	.5-.9	10	.75D1	0.00%	0.5	0.05	0.5	.5-.6
37	1.3	3	.25D1	0.00%	0.5	0.05	0.5	.5-.9	3	.25D1	0.00%	0.5	0.05	0.5	.5-.6
38		3	.75D1	0.00%	0.5	0.05	0.5	.5-.9	3	.75D1	0.00%	0.5	0.05	0.5	.5-.6
39		10	.25D1	0.00%	0.5	0.05	0.5	.5-.9	10	.25D1	0.00%	0.5	0.05	0.5	.5-.6
40		10	.75D1	0.00%	0.5	0.05	0.5	.5-.9	10	.75D1	0.00%	0.5	0.05	0.5	.5-.6
41	0.7	3	.25D1	0.00%	0.5	0.05	0.5	.5-.9	3	.25D1	3.50%	0.5	0.05	0.5	.5-.6
42		3	.75D1	0.00%	0.5	0.05	0.5	.5-.9	3	.75D1	3.50%	0.5	0.05	0.5	.5-.6
43		10	.25D1	0.00%	0.5	0.05	0.5	.5-.9	10	.25D1	3.50%	0.5	0.05	0.5	.5-.6
44		10	.75D1	0.00%	0.5	0.05	0.5	.5-.9	10	.75D1	3.50%	0.5	0.05	0.5	.5-.6
45	1.3	3	.25D1	0.00%	0.5	0.05	0.5	.5-.9	3	.25D1	3.50%	0.5	0.05	0.5	.5-.6
46		3	.75D1	0.00%	0.5	0.05	0.5	.5-.9	3	.75D1	3.50%	0.5	0.05	0.5	.5-.6
47		10	.25D1	0.00%	0.5	0.05	0.5	.5-.9	10	.25D1	3.50%	0.5	0.05	0.5	.5-.6
48		10	.75D1	0.00%	0.5	0.05	0.5	.5-.9	10	.75D1	3.50%	0.5	0.05	0.5	.5-.6

Table 4 (Cont'd)

49	0.7	3	.25D1	3.5%	0.5	0.05	0.5	.5-.9	3	.25D1	3.5%	0.5	0.05	0.5	.5-.6
50		3	.75D1	3.5%	0.5	0.05	0.5	.5-.9	3	.75D1	3.5%	0.5	0.05	0.5	.5-.6
51		10	.25D1	3.5%	0.5	0.05	0.5	.5-.9	10	.25D1	3.5%	0.5	0.05	0.5	.5-.6
52		10	.75D1	3.5%	0.5	0.05	0.5	.5-.9	10	.75D1	3.5%	0.5	0.05	0.5	.5-.6
53	1.3	3	.25D1	3.5%	0.5	0.05	0.5	.5-.9	3	.25D1	3.5%	0.5	0.05	0.5	.5-.6
54		3	.75D1	3.5%	0.5	0.05	0.5	.5-.9	3	.75D1	3.5%	0.5	0.05	0.5	.5-.6
55		10	.25D1	3.5%	0.5	0.05	0.5	.5-.9	10	.25D1	3.5%	0.5	0.05	0.5	.5-.6
56		10	.75D1	3.5%	0.5	0.05	0.5	.5-.9	10	.75D1	3.5%	0.5	0.05	0.5	.5-.6
57	0.7	3	.25D1	3.5%	0.5	0.05	0.5	.5-.9	3	.25D1	1.5%	0.5	0.05	0.5	.5-.6
58		3	.75D1	3.5%	0.5	0.05	0.5	.5-.9	3	.75D1	1.5%	0.5	0.05	0.5	.5-.6
59		10	.25D1	3.5%	0.5	0.05	0.5	.5-.9	10	.25D1	1.5%	0.5	0.05	0.5	.5-.6
60		10	.75D1	3.5%	0.5	0.05	0.5	.5-.9	10	.75D1	1.5%	0.5	0.05	0.5	.5-.6
61	1.3	3	.25D1	3.5%	0.5	0.05	0.5	.5-.9	3	.25D1	1.5%	0.5	0.05	0.5	.5-.6
62		3	.75D1	3.5%	0.5	0.05	0.5	.5-.9	3	.75D1	1.5%	0.5	0.05	0.5	.5-.6
63		10	.25D1	3.5%	0.5	0.05	0.5	.5-.9	10	.25D1	1.5%	0.5	0.05	0.5	.5-.6
64		10	.75D1	3.5%	0.5	0.05	0.5	.5-.9	10	.75D1	1.5%	0.5	0.05	0.5	.5-.6
65	0.7	3	.25D1	1.5%	0.5	0.05	0.5	.5-.9	3	.25D1	3.5%	0.5	0.05	0.5	.5-.6
66		3	.75D1	1.5%	0.5	0.05	0.5	.5-.9	3	.75D1	3.5%	0.5	0.05	0.5	.5-.6
67		10	.25D1	1.5%	0.5	0.05	0.5	.5-.9	10	.25D1	3.5%	0.5	0.05	0.5	.5-.6
68		10	.75D1	1.5%	0.5	0.05	0.5	.5-.9	10	.75D1	3.5%	0.5	0.05	0.5	.5-.6
69	1.3	3	.25D1	1.5%	0.5	0.05	0.5	.5-.9	3	.25D1	3.5%	0.5	0.05	0.5	.5-.6
70		3	.75D1	1.5%	0.5	0.05	0.5	.5-.9	3	.75D1	3.5%	0.5	0.05	0.5	.5-.6
71		10	.25D1	1.5%	0.5	0.05	0.5	.5-.9	10	.25D1	3.5%	0.5	0.05	0.5	.5-.6
72		10	.75D1	1.5%	0.5	0.05	0.5	.5-.9	10	.75D1	3.5%	0.5	0.05	0.5	.5-.6

Table 4 (Cont'd)

Scenarios 3-3.4

In the third set of scenarios different rates of continuous quality change are combined with discontinuous quality changes and advertising. In the first set of scenarios, 3.0, a discontinuous quality improvement for competitor one is compared with a continuous quality improvement trajectory for competitor two is combined with zero advertising levels so that the quality impact may be considered independently of advertising. In the second set, 3.1, different levels of advertising are combined with the same quality profiles as in scenario 3.0. In particular a heavy advertising rate is give to the firm with the discontinuous quality profile and no advertising is given to firm two. In the next set of scenarios, 3.2, heavy advertising is applied to the firm without any discontinuous quality jump. The fourth set of scenarios, 3.3, has the second firm introducing a discontinuous quality jump 5 years after the first's quality jump and has neither firms one nor two advertising. The fifth and last set of scenarios, 3.4, combines the quality profiles from scenario 3.3 and has the first firm begin heavy advertising in the year it introduces the discontinuous quality jump and firm two not advertising at all. The other parameters are held according to the above discussion and may be reviewed in Table 5.

#	COMPETITOR 1								COMPETITOR 2						
	e	D1	D2	A	β	α	δ	q	D1	D2	A	β	α	δ	q
1	0.7	3	.25D1	0.00%	0.5	0.05	0.5	.5 .25J5	3	.25D1	0.00%	0.5	0.05	0.5	.5-.6
2		3	.75D1	0.00%	0.5	0.05	0.5	.5 .25J5	3	.75D1	0.00%	0.5	0.05	0.5	.5-.6
3		10	.25D1	0.00%	0.5	0.05	0.5	.5 .25J5	10	.25D1	0.00%	0.5	0.05	0.5	.5-.6
4		10	.75D1	0.00%	0.5	0.05	0.5	.5 .25J5	10	.75D1	0.00%	0.5	0.05	0.5	.5-.6
5	1.3	3	.25D1	0.00%	0.5	0.05	0.5	.5 .25J5	3	.25D1	0.00%	0.5	0.05	0.5	.5-.6
6		3	.75D1	0.00%	0.5	0.05	0.5	.5 .25J5	3	.75D1	0.00%	0.5	0.05	0.5	.5-.6
7		10	.25D1	0.00%	0.5	0.05	0.5	.5 .25J5	10	.25D1	0.00%	0.5	0.05	0.5	.5-.6
8		10	.75D1	0.00%	0.5	0.05	0.5	.5 .25J5	10	.75D1	0.00%	0.5	0.05	0.5	.5-.6
9	0.7	3	.25D1	3.50%	0.5	0.05	0.5	.5 .25J5	3	.25D1	0.00%	0.5	0.05	0.5	.5-.6
10		3	.75D1	3.50%	0.5	0.05	0.5	.5 .25J5	3	.75D1	0.00%	0.5	0.05	0.5	.5-.6
11		10	.25D1	3.50%	0.5	0.05	0.5	.5 .25J5	10	.25D1	0.00%	0.5	0.05	0.5	.5-.6
12		10	.75D1	3.50%	0.5	0.05	0.5	.5 .25J5	10	.75D1	0.00%	0.5	0.05	0.5	.5-.6
13	1.3	3	.25D1	3.50%	0.5	0.05	0.5	.5 .25J5	3	.25D1	0.00%	0.5	0.05	0.5	.5-.6
14		3	.75D1	3.50%	0.5	0.05	0.5	.5 .25J5	3	.75D1	0.00%	0.5	0.05	0.5	.5-.6
15		10	.25D1	3.50%	0.5	0.05	0.5	.5 .25J5	10	.25D1	0.00%	0.5	0.05	0.5	.5-.6
16		10	.75D1	3.50%	0.5	0.05	0.5	.5 .25J5	10	.75D1	0.00%	0.5	0.05	0.5	.5-.6
17	0.7	3	.25D1	0.00%	0.5	0.05	0.5	.5 .25J5	3	.25D1	3.50%	0.5	0.05	0.5	.5-.6
18		3	.75D1	0.00%	0.5	0.05	0.5	.5 .25J5	3	.75D1	3.50%	0.5	0.05	0.5	.5-.6
19		10	.25D1	0.00%	0.5	0.05	0.5	.5 .25J5	10	.25D1	3.50%	0.5	0.05	0.5	.5-.6
20		10	.75D1	0.00%	0.5	0.05	0.5	.5 .25J5	10	.75D1	3.50%	0.5	0.05	0.5	.5-.6

Table 5– Scenarios 3 .0 to 3.4

#	COMPETITOR 1								COMPETITOR 2						
	e	D1	D2	A	β	α	δ	q	D1	D2	A	β	α	δ	q
21	0.7	3	.25D1	0.00%	0.5	0.05	0.5	.5 Y5	3	.25D1	0.00%	0.5	0.05	0.5	.5 Y10
26		3	.75D1	0.00%	0.5	0.05	0.5	.5 Y5	3	.75D1	0.00%	0.5	0.05	0.5	.5 Y10
27		10	.25D1	0.00%	0.5	0.05	0.5	.5 Y5	10	.25D1	0.00%	0.5	0.05	0.5	.5 Y10
28		10	.75D1	0.00%	0.5	0.05	0.5	.5 Y5	10	.75D1	0.00%	0.5	0.05	0.5	.5 Y10
29	1.3	3	.25D1	0.00%	0.5	0.05	0.5	.5 Y5	3	.25D1	0.00%	0.5	0.05	0.5	.5 Y10
30		3	.75D1	0.00%	0.5	0.05	0.5	.5 Y5	3	.75D1	0.00%	0.5	0.05	0.5	.5 Y10
31		10	.25D1	0.00%	0.5	0.05	0.5	.5 Y5	10	.25D1	0.00%	0.5	0.05	0.5	.5 Y10
32		10	.75D1	0.00%	0.5	0.05	0.5	.5 Y5	10	.75D1	0.00%	0.5	0.05	0.5	.5 Y10
33	0.7	3	.25D1	3.5%Y5	0.5	0.05	0.5	.5 Y5	3	.25D1	0.00%	0.5	0.05	0.5	.5 Y10
34		3	.75D1	3.5%Y5	0.5	0.05	0.5	.5 Y5	3	.75D1	0.00%	0.5	0.05	0.5	.5 Y10
35		10	.25D1	3.5%Y5	0.5	0.05	0.5	.5 Y5	10	.25D1	0.00%	0.5	0.05	0.5	.5 Y10
36		10	.75D1	3.5%Y5	0.5	0.05	0.5	.5 Y5	10	.75D1	0.00%	0.5	0.05	0.5	.5 Y10
37	1.3	3	.25D1	3.5%Y5	0.5	0.05	0.5	.5 Y5	3	.25D1	0.00%	0.5	0.05	0.5	.5 Y10
38		3	.75D1	3.5%Y5	0.5	0.05	0.5	.5 Y5	3	.75D1	0.00%	0.5	0.05	0.5	.5 Y10
39		10	.25D1	3.5%Y5	0.5	0.05	0.5	.5 Y5	10	.25D1	0.00%	0.5	0.05	0.5	.5 Y10
40		10	.75D1	3.5%Y5	0.5	0.05	0.5	.5 Y5	10	.75D1	0.00%	0.5	0.05	0.5	.5 Y10

Table 5 (cont'd)

CHAPTER 4

Simulation Results

Scenarios

In order to examine the results of the simulation under different conditions two values for the price elasticity of demand have been chosen, an inelastic value, 0.7 and an elastic one, 1.3. Two different values for the durability of the individual units are compared. This is the parameter D1. The first value is D1=3 years and the second is D1=10 years. Recognizing that the individual unit will have a limited time during which it influences sales in the market two different values for D2 are also used, D2=0.25D1 and D2=0.75D1. The first value of D2 sets the amount of time that the product influences future consumers to 25% of the total unit life and the second considers how sales are impacted if the unit influences sales for 75% of the unit life. The life of the product line is set to 20 years. The values for the amount of advertising and the quality trajectories depend on the individual scenario.

Scenarios 1.0 to 1.3

The scenarios in the first group examine the competitors with and without advertising. In addition to providing valuable information in and of them selves these scenarios will also provide a basis for comparison with the other scenarios.

Scenario 1.0

The first set scenario 1.0 runs 1-4 are made with an inelastic demand value of e=0.7. The quality trajectories are equal and constant. The initial price was offset so that the plots of the price trajectories would not be superimposed on one another. The results may be seen in Figure 6 to Figure 9. Please not that Figure 6 to Figure 9 are typical examples of simulation run results. Hereafter the results of the runs are included in Appendix 1 to 3.

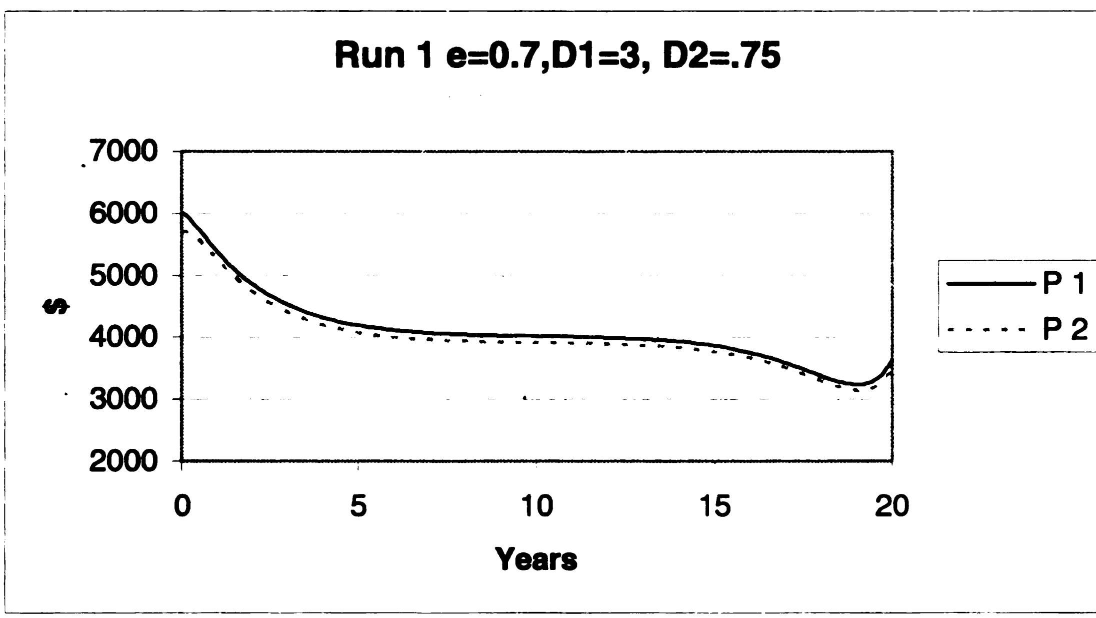


Figure 6 – Run 1 Scenario 1.0

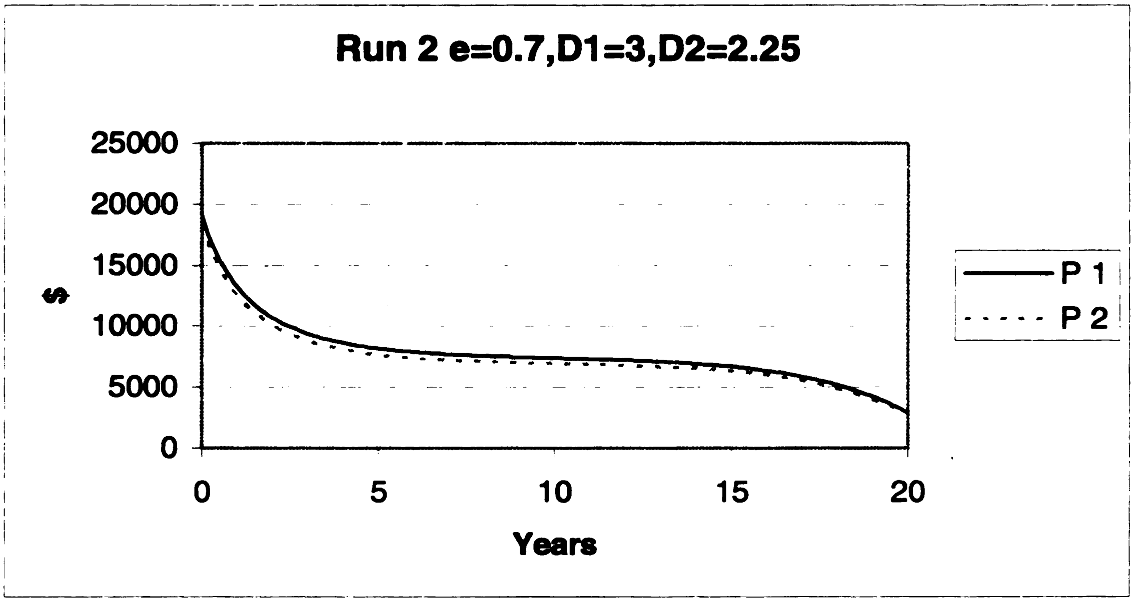


Figure 7 – Run 2 Scenario 1.0

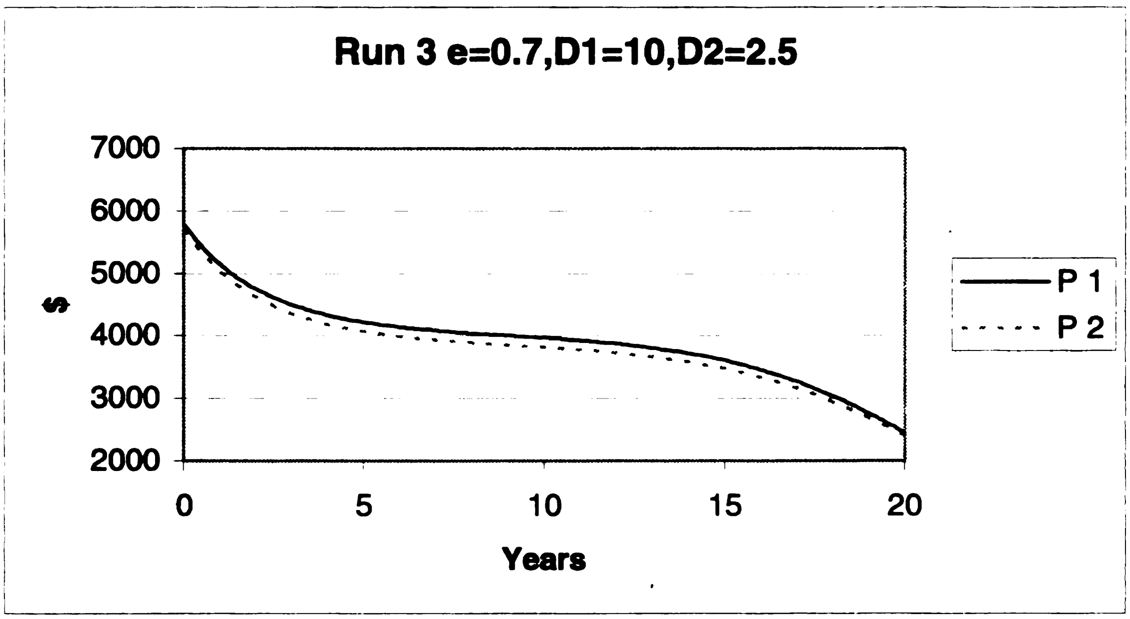


Figure 8 -Run 3 Scenario 1.0

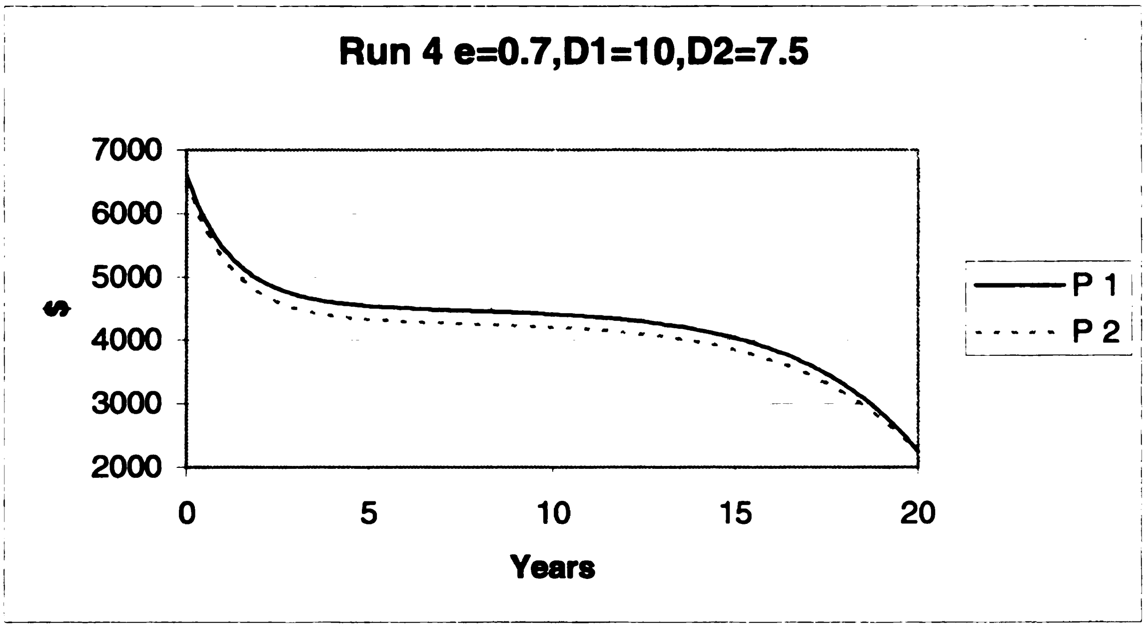


Figure 9 - Run 3 Scenario 1.0

While the prices are closely parallel to each other, as expected, there was a minor difference from the expected performance in that Competitor two was forced to lower its pricing to a greater extent then Competitor one during the middle of the 20 year product life cycle. It was also discovered that when the life expectancy was increased to 10 years there was more of on offset for the second competitor then when the life expectancy was set to 3 years. See figure 7 and 8. This difference was further amplified when the elasticity was set to a more elastic value of 1.3. See Figure 36 to Figure 39 Appendix 1.

It is also interesting to note that under inelastic conditions with a short unit life span and a relatively long period of influence for the quality weighted goods existing in the marketplace, see Figure 7, the price that maximizes profits for both firms is much greater than under other conditions. This is in agreement with Narasimhan and Mendez (2001) who found that a globally stable equilibrium exists when $q > \frac{1}{\alpha MD_2}$. Under these conditions they conclude that a higher maximum price level exists than under other conditions.

In order to establish that the difference was not an aberration in the model each of the original 8 runs in scenario 1.0 were run again with the initial cost values set equal to each other and all other parameters equal. Under these conditions the values were exactly superimposed.

The difference in price when the two prices are offset may be explained by the fact that the two products are substitute goods for one another. A decrease in the price of one reduces the demand for the substitute good. In order to compensate and increase its revenues the firm is forced to reduce its price. Furthermore the number of units, Q, in the market continues to have an impact on sales via diffusion. The result is that the firm with the higher price has fewer units in the market. In the case where both firms have equal quality profiles the only mechanism that the trailing firm has to overcome an initial sales difference is via a reduction in price. The response from the other firm is to lower its price thereby maintaining its advantage. This sales difference is shown in Figure 10.

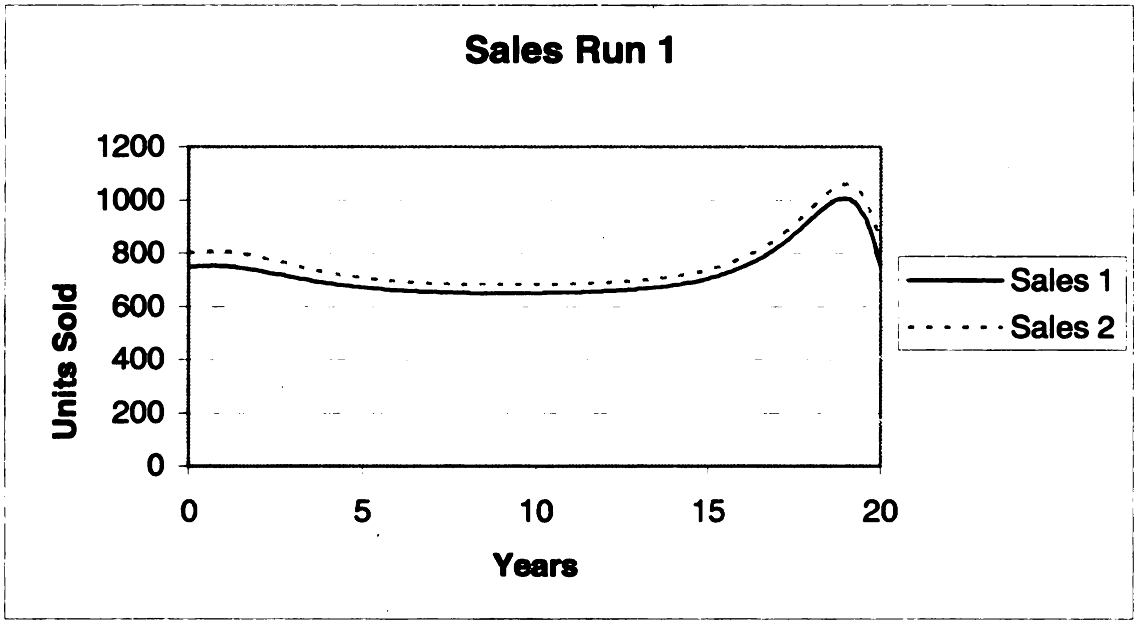


Figure 10 – Sales Run # 1

Scenario 1.1

The second set of scenarios in this group, scenario 1.1 runs 9-16, considers the impact advertising has on the price trajectory of a firm independently of competition. In addition to this identifying the amount of sales increase attributable to advertising these runs establish a baseline for comparison when advertising and competition are use in conjunction with each other. Eight separate simulation runs are made with the elasticity set to two different values, the unit duration set to two different values and the amount of time a unit continues to influence sales set to two different values. The price and market share for the first firm are allowed to obtain optimal values. The price and market share for the second firm are set and fixed to null values. The advertising for the firm is set to 1.7% of its revenues. This approximates the amount of money spent by the Ford Motor company on advertising over several years (Advertisers 1977-2003). The market penetration, Beta, is set to 0.5 and the effectiveness of the advertising is set to 0.05. These values are in keeping with the values found by Erickson (1991; 1997) in empirical studies of advertising. The quality trajectory of the firm varies continuously from 0.5 to 0.6 over the entire time horizon of 20 years. The results of these runs are shown in Figure 40 to Figure 43 Appendix 1.

The price trajectories under all conditions are the same as those without advertising and no competition, which is as expected. The percent added sales that are derived from the advertising are summarized in Table 6. Under both the elastic and inelastic conditions advertising has the least impact when the unit product durability is the least, 3 of 20 years and when the quality impact is the greatest percentage of this time, 75% of D1. Under both the elastic and inelastic conditions advertising has the most impact when the unit product durability is the greatest, 10 of 20 years and when the quality impact is the least, 25% of D1. This suggests that advertising has the most impact when the quality influence dissipates quickly relative to the life of the product. Managerially this means that if the quality durability does not continue to influence sales for a large percentage of the live of the product advertising expenditures show the most return. Conversely advertising expenditures are not as valuable if the quality durability remains persistent in the market.

SCENARIO 1.1			
Run #	Conditions	Total Sales	%Sales Increase from Ad
9	e=0.7,D1=3,D2=.75	143,161.5	3.37%
10	e=0.7,D1=3,D2=2.25	122,827.2	2.06%
11	e=0.7,D1=10,D2=2.5	91,452.56	6.03%
12	e=0.7,D1=10,D2=7.5	98,413.66	5.01%
13	e=1.3,D1=3,D2=.75	243,821.9	2.34%
14	e=1.3,D1=3,D2=.2.25	254,195.8	1.50%
15	e=1.3,D1=10,D2=2.5	145779.7	4.86%
16	e=1.3,D1=10,D2=7.5	156363.5	4.33%

Table 6– Sales increase due to Advertising

Scenario 1.2

The set of runs composing Scenario 1.2 numbers 17 to 24 are intended to examine the impact advertising has in a competitive environment. Scenario 1.3 will continue this analysis. For each competitor the quality trajectories are established as 0.5 to 0.6 continuously over the 20 year time horizon. Advertising penetration and effectiveness are set to 0.5 and 0.05 respectively. Advertising expenditures for the first competitor are set to 3.5% of revenue or an aggressive advertising effort as apposed to a normal one of 1.7% while the advertising rate for the second is set to zero. This is intended to amplify any impact for easy observation. The results of these runs are shown in Figure 44 to Figure 51 Appendix 1.

As clearly demonstrated by Figure 44 to Figure 51 advertising under these conditions has a minimal impact on the price trajectory initially and that further diminishes over time until the difference disappears. This minimal impact is due to two reasons. First advertising as developed here only addresses the market potential that has not been captured through the diffusion component and the price positions of the firms. This is further reduced by the effectiveness of the advertising and the advertising penetration. As a result the total potential of advertising into the untapped market is relatively small when compared with the total market potential. Second, the firm that is not advertising has the ability to overcome the disadvantage created by advertising by reducing its price so that its market potential increases and market share is maintained.

Scenario 1.3

The third set of scenarios in the first set, 1.3 runs 25 to 32 adds competitive advertising to the analysis. All conditions are kept the same as in scenario 1.2 but the second firm advertises at a rate of 1.7% of revenue. The results are seen in Figure 52 to Figure 59 Appendix 1.

Scenario 1.4

The last group of scenarios in the first set, scenario 1.4 runs 32 to 40 considers what happens when two firms have two different quality trajectories and two different advertising policies. Runs are made with two different price elasticity's, 0.7 and 1.3, two different unit lifetimes, 3 and 10, and two different period of time when quality has an impact on sales, 25% and 75% of the unit lifetimes D1. The quality trajectory of the first firm varies from 0.6 to 0.9. While the quality trajectory of the second firm remains constant at 0.75. Advertising for the first firm is set to 1.7% of revenues. The second firm advertises aggressively with advertising set to 3.5% of revenues. This is intended to model a case where one firm attempts to gain sales by improving its quality position while its competitor attempts to maintain sales with advertising expenditures alone. The results of these run may be seen in Figure 60 to Figure 67 Appendix 1. The quality profiles of the products may be seen in figure 42.

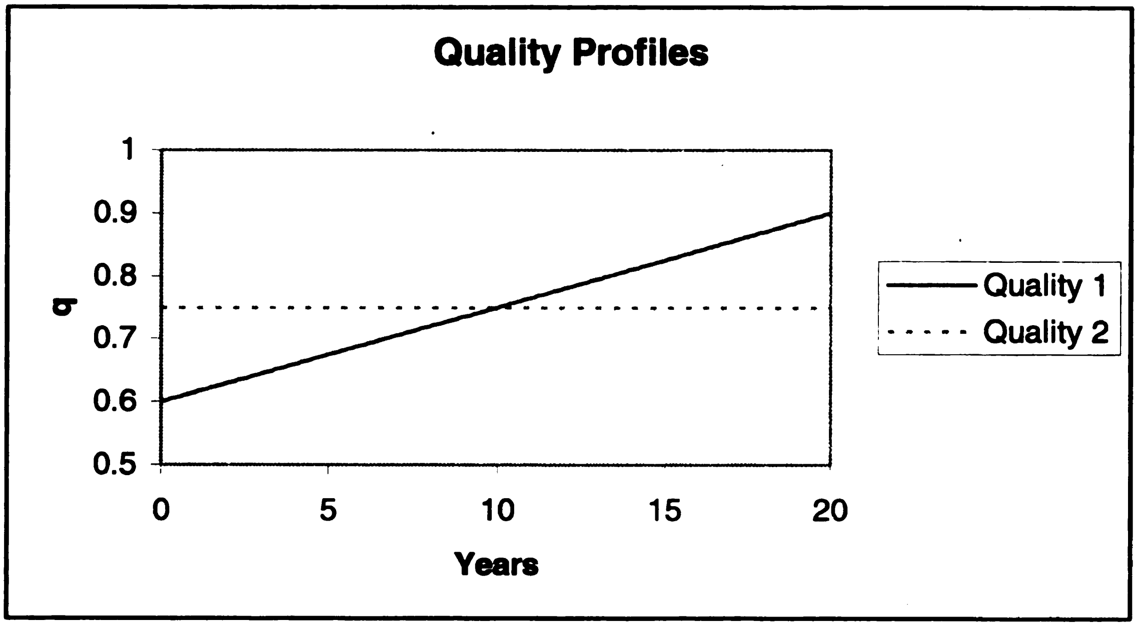


Figure 11 – Quality Profiles Scenario 1.4

In the inelastic cases the price trajectory for the second competitor remains relative close to that of the first competitor. Lowering the price to take advantage of its superior quality early in the time period is of small advantage to the second competitor since the change in price is greater than the change in demand. The quality advantage allows the firm to keep a higher price and retain market share despite the fact that it only has a quality advantage for 10 of the 20 year time horizon. Competitor two is able to actually raise its price when the life of the product is short and the length of time that the quality influences purchase decisions is small. This situation exists for only the first 5 years of the time horizon. After that the quality difference is diminishing for competitor two and is detrimental to it for the second 10 years of the time horizon.

In the elastic cases the price trajectory for the second competitor differs more from that of the first competitor. In these cases where a price change is less than the change in demand profits may be maximized by lowering the purchase price and increasing market share in combination with the existing quality advantage. In the two cases where the life of the unit is much less then the life of the product line maximizes its profits by pricing its product less than that of competitor one. In the two cases where the life of the product line is closer to the life of the unit the price positions reverse each other. Competitor one maximizes its sales by lowering its price below that of competitor two. In both cases this occurs after the quality advantage has shifted to the first competitor.

It should also be noted here that in both elastic and inelastic cases when the unit life is very short relative to the time horizon and the influence of existing units in the market is short both firms increase their prices for a short period before decreasing them. Increases in price were seen in the original NGM model (Narasimhan et al. 1993; Narasimhan et al. 1996) but under different time constraints. The explanation comes from the different quality trajectories in a competitive environment. Initially the quality superiority of the second competitor allows it to command a higher price relative to the first competitor. Firm one follows the price increase to maximize its profits. As this differential decays the second firm is forced to lower its price to gain market share and the first firm is also forced to lower its prices so as not to lose market share.

Scenarios 2.0-2.8

The runs in the second set of scenarios continues the consideration of the interaction of competition and how it impacts the price trajectory for the two competitors when different quality trajectories are used by the competitors. The runs also add advertising interactions into the analysis once more information is collected on competition and quality interactions.

Scenario 2.0

In the group of runs in the first scenario 2.0, runs 1 to 8, the quality for the first competitor is varied from 0.5 to 0.9 while the quality varies from 0.5 to 0.6 for the second. See Figure 12. This represents the situation where one company seeks actively to improve its product quality and the second accepts only those quality improvements that result from learning how to produce the product better over time without any added effort or TQM policy. The advertising in these runs is turned off so that the interaction may be considered without any extenuating circumstances. In later groups of runs the advertising function will be restored and the interaction between competition and advertising considered. The two levels of elasticity that have been examined before in this work will be considered again, 0.7 and 1.3. Two different product life spans will be examined, 3 years and 10 years, and in each case two different lengths of time that the individual units influence sales will be used. These runs are shown in Figure 68 to Figure 75 Appendix 2. The sales figures for the two competitors under the four conditions are reported in Figure 13 to Figure 16.

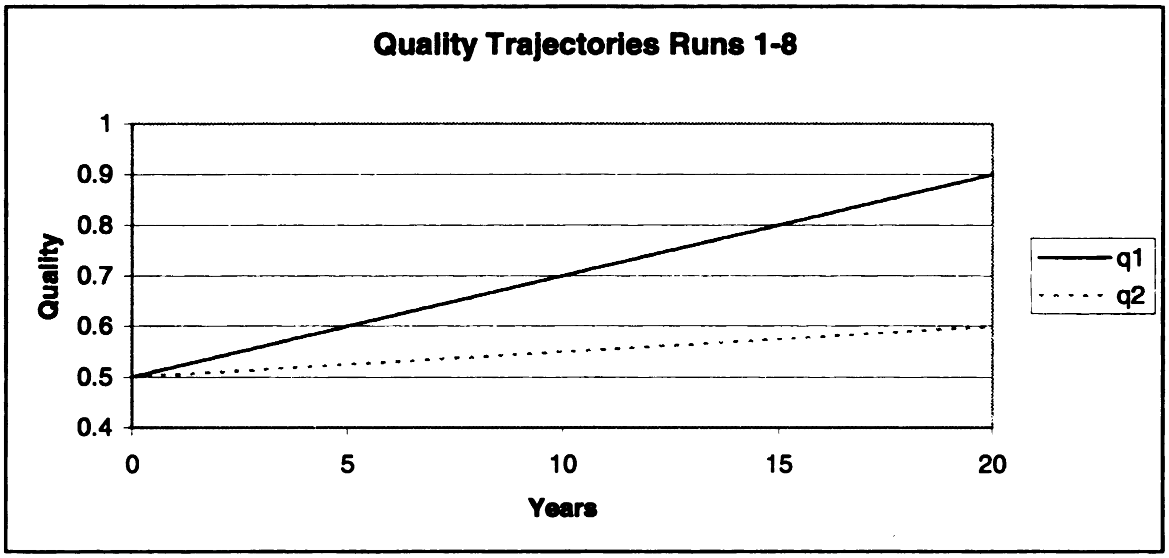


Figure 12 – Quality Trajectories Runs 1-8

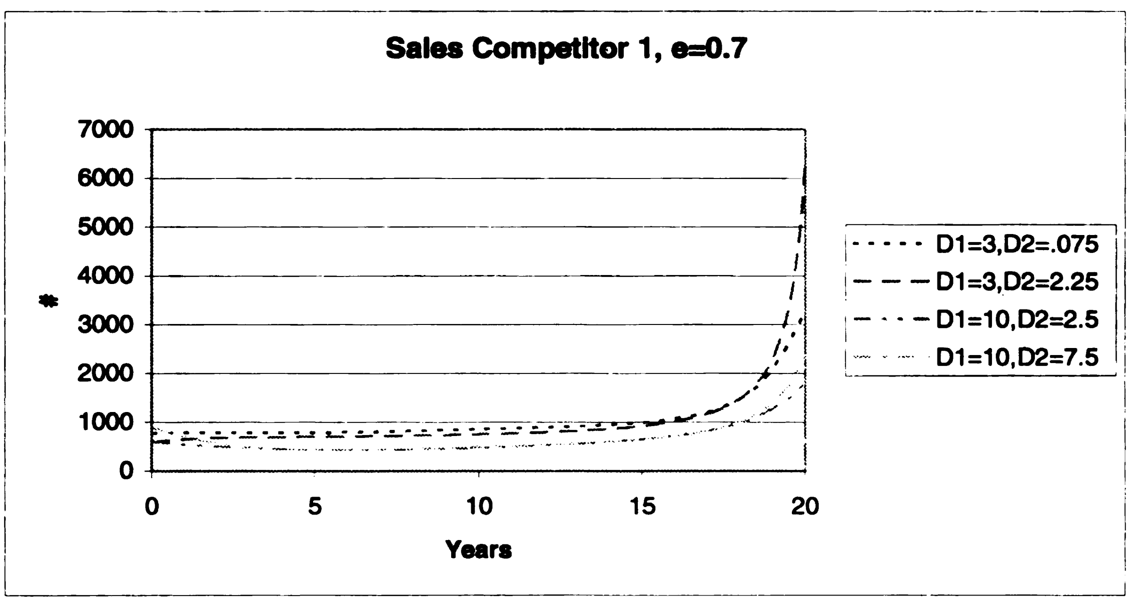


Figure 13- Sales Competitor 1, e=0.7

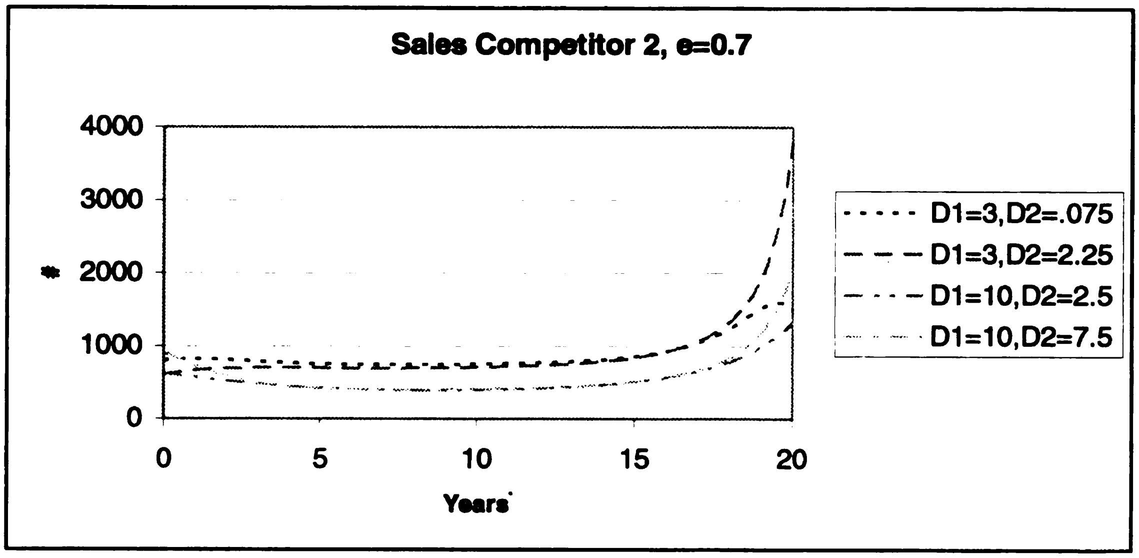


Figure 14 - Sales Competitor 2, e=0.7

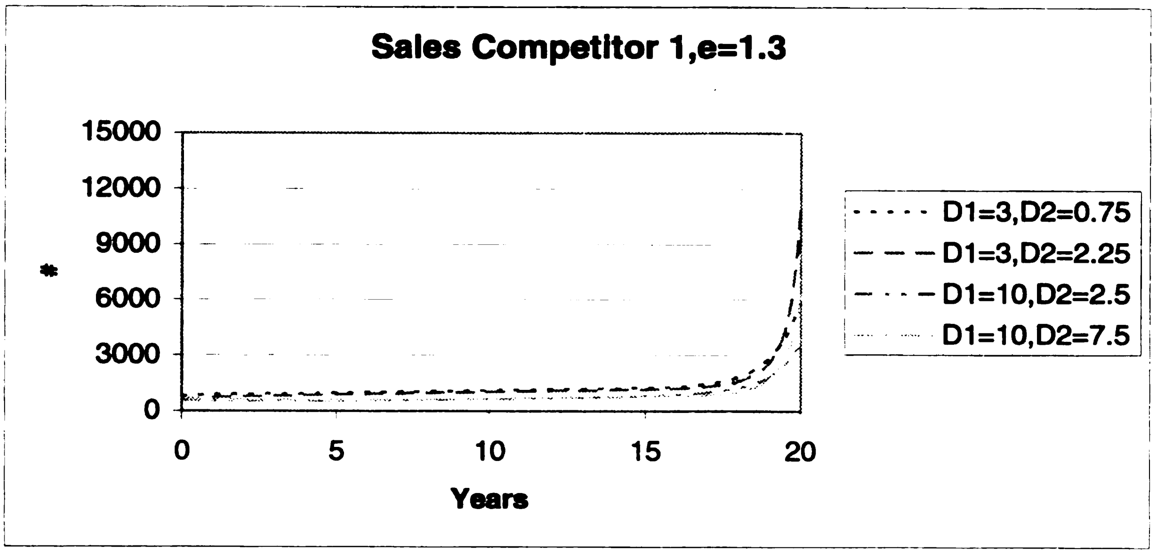


Figure 15 - Sales Competitor 1, e=1.3

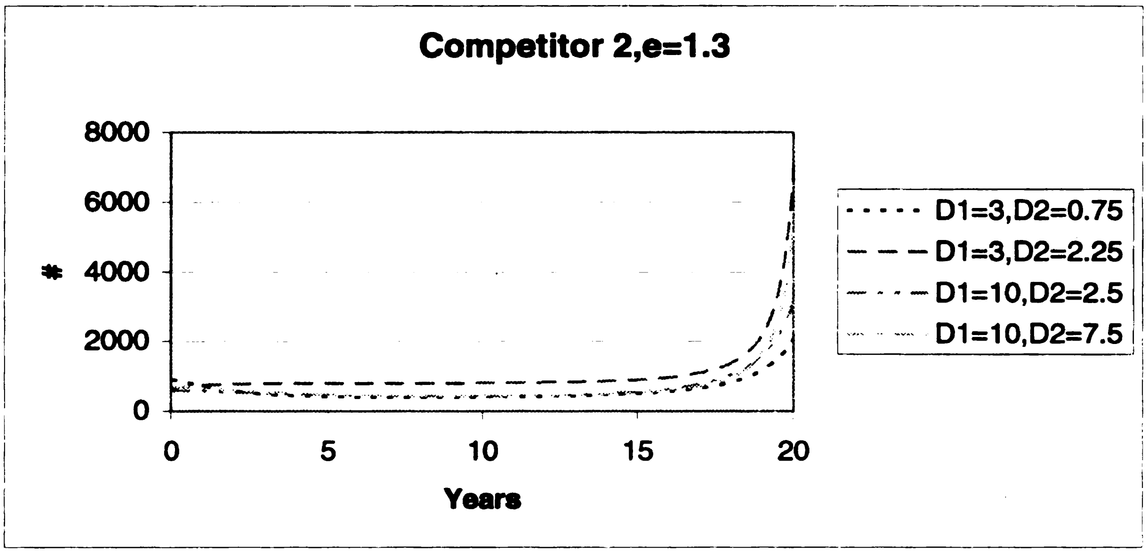


Figure 16 - Sales Competitor 2, e=1.3

In all cases both when the price elasticity of the product is elastic and inelastic the price for the two competitors declines over time. There is a difference in the response of the second competitor when the life of the individual unit is much smaller than the life of the product line, D1=3. In these cases the second competitor maintains a price level lower than the first competitor until late in the total product life cycle. At that time the second competitor, who has by then developed a marked deficit in product quality, begins to charge a price that exceeds that of the first competitor. It is no longer able to command an increase in sales by lowering price alone. This behavior is seen in all runs to a greater or lesser degree.

This behavior is reflected in the sales plots where it can clearly be seen that sales toward the end of the product life cycle greatly favor competitor one. The prices for the second competitor plateaus before the lower prices of competitor one forces them down again. Profits are maximized without any attempt being made to match the reduction in price that the first competitor is able to enact. In the inelastic cases where the percent change in demand is less than the percent change in price the second competitor is able to maintain a price relatively close to that of the first competitor. This price differential is greater in all four cases when the product price is elastic. Sales in these cases for the first competitor greatly outstrip those of the second. The profits for all four cases normalized to one are shown in Table 7.

	e=0.7				e=1.3			
	D1=3, D2=0.75	D1=3, D2=2.25	D1=10, D2=2.5	D1=10, D2=7.5	D1=3, D2=0.75	D1=3, D2=2.25	D1=10, D2=2.5	D1=10, D2=7.5
Profit 1	1.277	1.101	1.171	1.119	1.310	1.114	1.132	1.061
Profit 2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 7– Relative profits Run 1-8 Scenario 2.0

As can be seen in Table 7 the firm with the superior quality improvements shows a greater profitability over the life of the product line. In both the elastic and inelastic cases the lowest profit advantage is seen when the product life is short and the influence of the existing units in the market is long relative to that life, an inverse relationship. This is in agreement with Narasimhan and Mendez (2001). When there is a continuous improvement in quality the earlier goods are of a lower quality level and if their influence is extended over a large percentage of the life of the unit the new superior quality unit will not be able to influence sales due to the residual impact from the lower quality goods.

Scenarios 2.1- 2.2

These scenarios examine the influence has when the quality trajectories differ substantially. The first competitor has a quality trajectory that ranges from 0.35 to 0.9 and the second has one ranging from 0.5 to 0.6. This mirrors the first scenario in that one competitor makes a concerted effort to improve its quality position while the second makes no special effort beyond learning improvements. They differ in that the first company begins with a marked quality deficit and finishes with a superior quality position. The advertising contributions fall into two categories. In scenario 2.1 the first company makes no effort to improve its sales position via advertising while in scenario 2.2 it makes a concerted effort to improve sales with a strong (expensive) advertising campaign. In both scenarios the second firm makes no effort to advertise choosing to remain complacent. Consistently with the other simulation runs in this dissertation two price elasticity's are used, 0.7 and 1.3. Two unit life times are used 3 and 10 years, and a fixed 20 year time horizon is used. Two periods of time where the quality of existing units in the market place influence sales, 0.25*D1 and 0.75*D1, are used. The price trajectories are shown in Figure 76-Figure 91 Appendix 2.

The relative profits realized by both firms are shown in Table 8 normalized to the profits of company two. Table 8 also shows the increase in profits due to the advertising efforts of competitor one in scenario 2.2 when its advertising is set to 3.5% of revenues.

CONDITIONS	AD $	PROFIT COMP 1 COMPARED TO COMP 2	PROFIT COMP 2	% INCREASE	3.5%VS. 1.7%
e=0.7,D1=3,D2=0.75	0.0%	0.996	1.000	-0.35%	
e=0.7,D1=3,D2=2.25	0.0%	1.000	1.000	0.04%	
e=0.7,D1=10,D2=2.5	0.0%	1.059	1.000	5.91%	
e=0.7,D1=10,D2=7.5	0.0%	1.054	1.000	5.45%	
e=1.3,D1=3,D2=0.75	0.0%	1.036	1.000	3.59%	
e=1.3,D1=3,D2=2.25	0.0%	1.035	1.000	3.47%	
e=1.3,D1=10,D2=2.5	0.0%	1.137	1.000	13.65%	
e=1.3,D1=10,D2=7.5	0.0%	1.119	1.000	11.93%	
e=0.7,D1=3,D2=0.75	3.5%	1.013	1.000	1.34%	1.70%
e=0.7,D1=3,D2=2.25	3.5%	1.010	1.000	1.00%	0.96%
e=0.7,D1=10,D2=2.5	3.5%	1.079	1.000	7.87%	1.96%
e=0.7,D1=10,D2=7.5	3.5%	1.072	1.000	7.20%	1.75%
e=1.3,D1=3,D2=0.75	3.5%	1.054	1.000	5.43%	1.84%
e=1.3,D1=3,D2=2.25	3.5%	1.046	1.000	4.60%	1.13%
e=1.3,D1=10,D2=2.5	3.5%	1.155	1.000	15.53%	1.88%
e=1.3,D1=10,D2=7.5	3.5%	1.134	1.000	13.40%	1.48%

Table 8– Relative profits Scenarios 2.1 and 2.2

The results clearly indicate the advantage quality improvements may make in corporate revenues. The two quality trajectories intersect at year ten when the two values are equal to 0.55. See Figure 17. This means that for the first half of the time horizon competitor 2 has a quality advantage and for the second half competitor 1 has an advantage. The relative profits show that competitor one has an advantage in all but two situations, inelastic price conditions and short unit life spans where it appears that there is no advantage gained form its increasing quality trajectory.

This lack of improvement in profitability is attributable to the symmetry of the

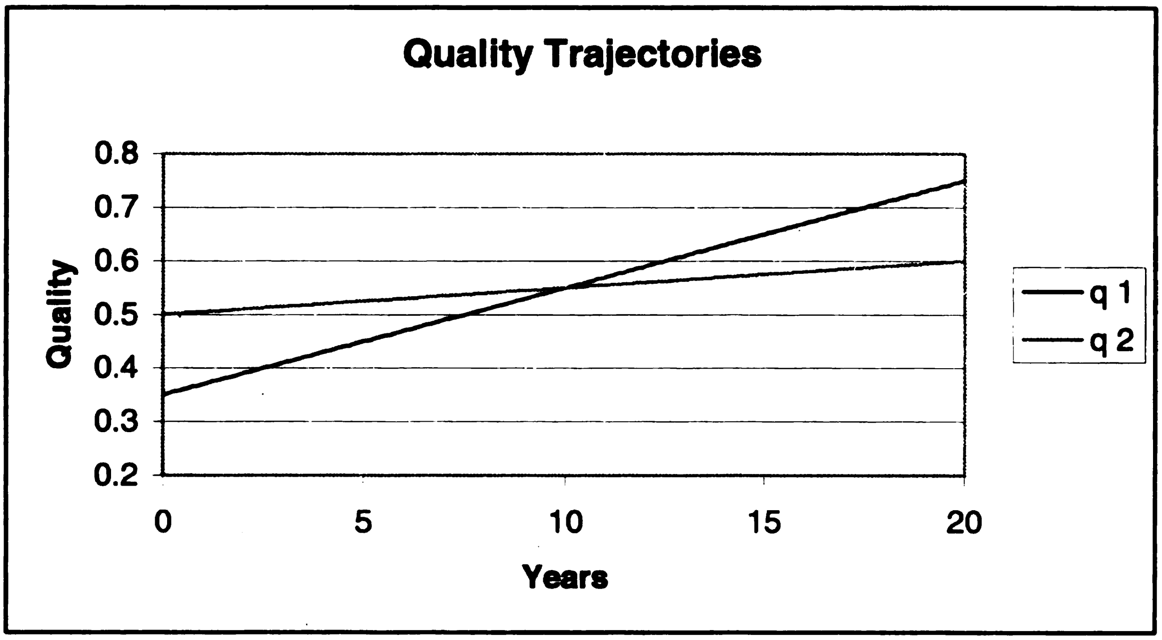


Figure 17 – Quality Competitors 1 and 2

situation. Each firm has a quality advantage 50% of the time and the short unit life times under inelastic conditions do not allow profits to be recovered in the second half of the scenario by the company with a superior quality position.

However, the increase in profits for competitor one under the other conditions, longer unit life spans and an elastic demand environment cannot be attributed to a generally superior quality position either. Since each firm has an equal amount of time when their products have a superior quality position, the increase in profitability must be a result of the increasing quality over the entire life of the product and the conditions under which it is sold. In the two inelastic cases where the unit life is long relative to the time horizon increased profits are seen for competitor one. Longer lived products mean that they must be replaced more frequently when the quality for competitor one has increased to a greater extent then in the short time period cases. In the four elastic cases while greater profits are seen in all four situations. In the case of the two short lived unit situations the elastic conditions allow a greater increase in demand relative to the increase in price so superior quality goods will command a grater relative price as they replace older units. In the two cases where the unit lives are long the units must be replaced after the quality improvements have been implemented.

The advertising impact for these situations may be seen in the increase in profits seen in the scenario 2.2 runs relative to scenario 2.1 runs. See Table 8. These increases exist in all cases and range from 0.96% to 1.88% depending on the conditions. Advertising is most effective in an elastic environment with a long unit life span and short quality influence periods and least effective in an inelastic environment with a short unit life span and a relatively long periods where the quality of previous units influence sales. This indicates that while quality improvements are effective under most conditions at increasing relative profits they may be assisted with an advertising campaign in all conditions. These campaigns however, are most effective with a long unit life span and relative short periods where existing units influence sales. This suggests that the use of quality as a strategic lever may be improved by the judicious use of advertising expenditures.

Scenarios 2.3-2.8

To further test this position scenarios 2.3 to 2.5 examine two different quality trajectories for the two competitors and six different advertising positions. The quality trajectories are initiated at the same level 0.5, giving neither competitor an initial advantage. The trajectory of the first competitor improves from 0.5 to 0.9. The trajectory of the second competitor improves from 0.5 to 0.6 this represents the aggressive and passive efforts at quality improvement as described before. The advertising positions are 3.5% vs. 0.0%, 0.0% vs. 0.0%, 0.0% vs.3.5%, 3.5% vs. 3.5%, 3.5% vs.1.5% and 1.5% vs. 3.5% respectively. These represent three situations. First, when a firm aggressively supports its quality improvement policy against a passive advertising competitor. Second, when a firm relies simply on its quality improvement, e.g. is passive relative to advertising and is competing against a passive advertising competitor. The third case is when a firm is passive relative to advertising but is competing against a competitor who is aggressively attempting to counter the quality strategy of the first with its advertising. Conditions are the same as in prior simulation runs e=0.7 and 1.3, D1 is 3 and 10, D2 is 0.25*D1 and 0.75*D1. The price trajectories for these run are shown in Figure 92 to Figure 139 Appendix 2. The quality trajectories are the same as in Scenario 2.0 Runs 1-8. See Figure 12.

The price trajectories follow patterns similar to those seen previously. The firm with the greater rate of quality increase is able to lower prices continuously while the competitive firm can only lower prices until the quality difference reaches a critical level. At that point it is unable to lower prices and maintain profitability. After this time it maintains its price level and begins to charge more for its product than the first competitor. As the end of the product life cycle approaches the first competitor begins to radically lower prices and the second firm is forced to lower prices again so that it may maintain market share supporting its profitability. The quality advantage allows for a lower price position and therefore increased profitability. Table 9 shows the three scenarios as run demonstrating the increase in profits from quality and advertising. Scenario 2.4 is the case where there is no advertising.

Scenario 2.3 shows the aggressive advertising for the competitor with the greatest rate of quality change, e.g. competitor 1 and Scenario 2.5 shows the aggressive advertising for the competitor with the lowest rate of quality change, competitor 2. Table 9 shows a comparison when either one firm or neither firm advertises. Table 10, scenarios 2.6-2.8 shows the differences when both firms advertise at some level and compares these values to the case when neither firm advertises.

RUN	AD RATIO	CONDITIONS	PROFITS 1	PROFITS 2	NET % DIFF	DIFF.
Scenario 2.3	3.5/0.0	e=0.7,D1=3,D2=0.75	1.294	1.000	29.41%	1.752%
	3.5/0.0	e=0.7,D1=3,D2=2.25	1.111	1.000	11.09%	0.945%
	3.5/0.0	e=0.7,D1=10,D2=2.5	1.192	1.000	19.21%	2.092%
	3.5/0.0	e=0.7,D1=10,D2=7.5	1.137	1.000	13.72%	1.862%
	3.5/0.0	e=1.3,D1=3,D2=0.75	1.330	1.000	33.03%	1.994%
	3.5/0.0	e=1.3,D1=3,D2=2.25	1.125	1.000	12.48%	1.124%
	3.5/0.0	e=1.3,D1=10,D2=2.5	1.152	1.000	15.20%	1.974%
	3.5/0.0	e=1.3,D1=10,D2=7.5	1.077	1.000	7.70%	1.587%
Scenario 2.4	0.0/0.0	e=0.7,D1=3,D2=0.75	1.277	1.000	27.66%	-
	0.0/0.0	e=0.7,D1=3,D2=2.25	1.101	1.000	10.15%	-
	0.0/0.0	e=0.7,D1=10,D2=2.5	1.171	1.000	17.12%	-
	0.0/0.0	e=0.7,D1=10,D2=7.5	1.119	1.000	11.86%	-
	0.0/0.0	e=1.3,D1=3,D2=0.75	1.310	1.000	31.03%	-
	0.0/0.0	e=1.3,D1=3,D2=2.25	1.114	1.000	11.35%	-
	0.0/0.0	e=1.3,D1=10,D2=2.5	1.132	1.000	13.22%	-
	0.0/0.0	e=1.3,D1=10,D2=7.5	1.061	1.000	6.11%	-
Scenario 2.5	0.0/3.5	e=0.7,D1=3,D2=0.75	1.254	1.000	25.38%	-2.28%
	0.0/3.5	e=0.7,D1=3,D2=2.25	1.090	1.000	9.04%	-1.10%
	0.0/3.5	e=0.7,D1=10,D2=2.5	1.148	1.000	14.75%	-2.36%
	0.0/3.5	e=0.7,D1=10,D2=7.5	1.099	1.000	9.85%	-2.00%
	0.0/3.5	e=1.3,D1=3,D2=0.75	1.285	1.000	28.51%	-2.52%
	0.0/3.5	e=1.3,D1=3,D2=2.25	1.100	1.000	10.00%	-1.36%
	0.0/3.5	e=1.3,D1=10,D2=2.5	1.110	1.000	11.02%	-2.20%
	0.0/3.5	e=1.3,D1=10,D2=7.5	1.044	1.000	4.38%	-1.73%

Table 9– Profitability differential from advertising

RUN #	AD $	CONDITIONS	COMP 1	COMP 2	NET % DIFF	% DIFF DUE TO AD
Scenario 2.6	3.5/3.5	e=0.7,D1=3,D2=0.75	1.271	1	27.10%	-0.56%
	3.5/3.5	e=0.7,D1=3,D2=2.25	1.098	1	9.80%	-0.35%
	3.5/3.5	e=0.7,D1=10,D2=2.5	1.168	1	16.80%	-0.32%
	3.5/3.5	e=0.7,D1=10,D2=7.5	1.117	1	11.70%	-0.16%
	3.5/3.5	e=1.3,D1=3,D2=0.75	1.305	1	30.50%	-0.53%
	3.5/3.5	e=1.3,D1=3,D2=2.25	1.124	1	12.40%	1.05%
	3.5/3.5	e=1.3,D1=10,D2=2.5	1.132	1	13.20%	-0.02%
	3.5/3.5	e=1.3,D1=10,D2=7.5	1.071	1	7.10%	0.99%
Scenario 2.7	3.5/1.5	e=0.7,D1=3,D2=0.75	1.2842	1	28.42%	0.76%
	3.5/1.5	e=0.7,D1=3,D2=2.25	1.1062	1	10.62%	0.47%
	3.5/1.5	e=0.7,D1=10,D2=2.5	1.1817	1	18.17%	1.05%
	3.5/1.5	e=0.7,D1=10,D2=7.5	1.1285	1	12.85%	0.99%
	3.5/1.5	e=1.3,D1=3,D2=0.75	1.3128	1	31.28%	0.25%
	3.5/1.5	e=1.3,D1=3,D2=2.25	1.1189	1	11.89%	0.54%
	3.5/1.5	e=1.3,D1=10,D2=2.5	1.1424	1	14.24%	1.02%
	3.5/1.5	e=1.3,D1=10,D2=7.5	1.0694	1	6.94%	0.83%
Scenario 2.8	1.5/3.5	e=0.7,D1=3,D2=0.75	1.2611	1	26.11%	-1.55%
	1.5/3.5	e=0.7,D1=3,D2=2.25	1.0944	1	9.44%	-0.71%
	1.5/3.5	e=0.7,D1=10,D2=2.5	1.1562	1	15.62%	-1.50%
	1.5/3.5	e=0.7,D1=10,D2=7.5	1.1063	1	10.63%	-1.23%
	1.5/3.5	e=1.3,D1=3,D2=0.75	1.2934	1	29.34%	-1.69%
	1.5/3.5	e=1.3,D1=3,D2=2.25	1.1047	1	10.47%	-0.88%
	1.5/3.5	e=1.3,D1=10,D2=2.5	1.1184	1	11.84%	-1.38%
	1.5/3.5	e=1.3,D1=10,D2=7.5	1.0503	1	5.03%	-1.08%

Table 10 Profitability differential from advertising 2

Clearly advertising increases the percentage of increased profits seen by the firm with the greater rate of quality improvement and counter advertising decreases that percentage of increased profits. This is as expected. What was unexpected is that the maximum assistance to sales for the high quality competitor and the maximum assistance to sales for the low quality competitor occurred under different conditions.

The basic quality advantage was maximized with advertising in all six scenarios under elastic price conditions, short unit life spans and short periods of influence. The profit advantage to competitor one was minimized due to the competitors advertising under relatively low price elasticizes, long life spans and long periods of product influence. The extream cases when one firm advertises and the other does not are shown in Table 11 and Table 12

	Ad $	Conditions	Comp 1	Comp 2	% Diff
Max	3.5/0.0	e=1.3,D1=3,D2=0.75	1.33	1	1.99%
Min	3.5/0.0	e=1.3,D1=10,D2=7.5	1.077	1	1.59%
Max	0.0/0.0	e=1.3,D1=3,D2=0.75	1.31	1	-
Min	0.0/0.0	e=1.3,D1=10,D2=7.5	1.061	1	-
Max	0.0/3.5	e=1.3,D1=3,D2=0.75	1.285	1	-2.52%
Min	0.0/3.5	e=1.3,D1=10,D2=7.5	1.044	1	-1.73%

Table 11 - Max and Min quality profit increases

Note that this differs somewhat from the last situation in that there is no quality deficit to overcome; it is purely a quality improvement situation. While both the minimum sales assistances due to advertising came

	Ad $	Conditions	Comp 1	Comp 2	% Diff
Min	3.5/0.0	e=0.7,D1=3,D2=2.25	1.111	1	0.95%
Max	3.5/0.0	e=0.7,D1=10,D2=2.5	1.192	1	2.09%
Min	0.0/3.5	e=0.7,D1=3,D2=2.25	1.09	1	-1.10%
Max	0.0/3.5	e=1.3,D1=3,D2=0.75	1.285	1	-2.52%

Table 12- Advertising assistance

under inelastic environments the maximums came under different environmental conditions. It should be noted here that minimum in the case of counter advertising is the least amount of reduction in the profits generated by firm one when firm two is using advertising to counter the quality strategic lever of firm one. In the elastic environment with short unit lives and relative long quality influence the aggressive advertising by competitor two allows it to install a larger product base before the quality differential becomes great. The elastic environment also allows it to increase prices without the penalty in demand that it would incur in an inelastic environment. When firm one pursues its quality strategy in a market where the units are not replaced frequently with respect to the time horizon advertising allows it to enhance the sales in the second half of the time horizon when it has a greater quality advantage. The inelastic environment reduces the ability of the second firm to respond to quality and advertising with a purely priced based strategy.

Scenarios 3.0-3.4

The forty runs in the last set of scenarios add discontinuous quality improvements into the analysis. A discontinuous improvement may be viewed as some radical change to the operational process or the product. This might take the form of a new type of production equipment reducing imperfections or a new addition to the product itself such as a new power train in an automobile. An example of this type of improvement is shown in Figure 18.

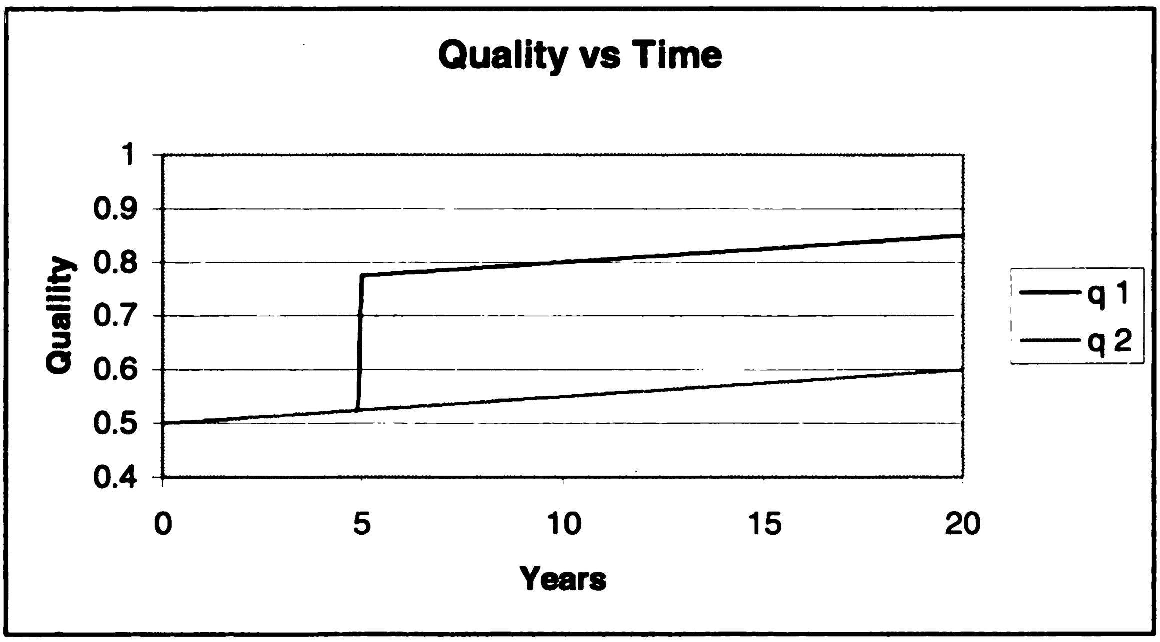


Figure 18 – Discontinuous Quality

In this example the first company introduces such a change in year five of the time horizon while company two makes no radical improvements in their process. In the first three scenarios advertising is considered in three ways. First, neither firm makes any advertising effort. This provides a baseline to see what the discontinuous quality improvement alone contributes to the relative profits of the firm making the change as opposed to those of the firm making no radical improvements. Second, Advertising is added to the firm making the changes to explore what kind of a profit improvement they might see when aggressive advertising their product while also making the quality improvement. Third, the firm making the improvement uses no advertising to support their market position in addition to the quality improvement while the second firm counters the discontinuous change with advertising alone. In the fourth scenario the second firm counters the discontinuous quality improvement with an improvement of their own after the first has made their improvement. In the fifth scenario quality improvements are introduced in the same manner but the first firm begins an aggressive advertising campaign at the same time that they introduce the improvement.

Scenario 3.0

In this scenario the quality profile for competitor one begins at 0.5 continues smoothly until year five and then improves by 0.25. It then continues smoothly to a value of 0.85. 0.85 was chosen as a terminus since the continuous improvement until year five proceeded at this steady rate. The quality profile for the second competitor moves from 0.5 to 0.6 this is at the same rate that the initial and final improvements are made by company one. Advertising for both firms is held to zero. Two different elasticity's are tested, 0.7 and 1.3. Two different unit lives are considered 10 and 3 years and the length of time that units in the marketplace continue to influence sales are 75% and 25% of these times. The terminal time horizon is 20 years. The price trajectories for these runs are shown in Figure 140-Figure 147 Appendix 3.

Prices decay in all eight cases. The price trajectory of competitor one shows a discontinuous change in year five when the quality change is introduced. Furthermore it shows a minor increase in price just before the quality discontinuity is introduced. In the two cases where the unit life is short relative to the time horizon and the length of time that units in the marketplace influence sales is short, 0.25*D1, the reduction in price is the most radical followed by a rapid increase in price with a steady decline in price continuing from that point. See Figure 140 and Figure 144. The price trajectory of competitor two begins below that of competitor one and eventually crosses that of competitor one so that it is charging a higher price than competitor one. This cross over occurs more rapidly in the elastic cases and the price differential is greater in these cases relative to the inelastic cases. This indicates that when the percent change in demand is less than the percent change in price the first competitor is unable to take full advantage of its quality position due to the limitations imposed by the substitute good in the market. The profits, normalized to competitor two, are shown in Table 13.

RUN #	CONDITIONS	PROFITS 1	PROFITS 2
Run 1	e=0.7,D1=3,D2=0.75	1.337	1.000
Run 2	e=0.7,D1=3,D2=2.25	1.123	1.000
Run 3	e=0.7,D1=10,D2=2.5	1.206	1.000
Run 4	e=0.7,D1=10,D2=7.5	1.141	1.000

Run 5	e=1.3,D1=3,D2=0.75	1.375	1.000
Run 6	e=1.3,D1=3,D2=2.25	1.133	1.000
Run 7	e=1.3,D1=10,D2=2.5	1.150	1.000
Run 8	e=1.3,D1=10,D2=7.5	1.076	1.000

Table 13– Profits Runs 1-8 Scenario 3

Under all conditions the firm with the discontinuous quality improvement. The greatest profit advantage seen by competitor one occurs when the conditions in the market are elastic and the product life is the shortest and the influence of existing units is also the shortest Run 5 in Table 13. The least amount of profit advantage seen by competitor one occurs when the conditions in the market are elastic and the unit life is greatest with the longest amount of time during which the existing units in the market have influence on sales. This is the same as Scenario 2.4. Note also that when comparing the continuous quality improvement case and the

	CONT CASE	DISCONTINOUS CASE	CONT CASE	DISCONTINOUS CASE
Conditions	0.5-0.9	0.5-0.85	0.5-0.9	0.5-0.85
e=0.7,D1=3,D2=0.75	1.277	1.337266	27.66%	33.73%
e=0.7,D1=3,D2=2.25	1.101	1.12328	10.15%	12.33%
e=0.7,D1=10,D2=2.5	1.171	1.205561	17.12%	20.56%
e=0.7,D1=10,D2=7.5	1.119	1.1413	11.86%	14.13%
e=1.3,D1=3,D2=0.75	1.31	1.374603	31.03%	37.46%
e=1.3,D1=3,D2=2.25	1.114	1.133166	11.35%	13.32%
e=1.3,D1=10,D2=2.5	1.132	1.149707	13.22%	14.97%
e=1.3,D1=10,D2=7.5	1.061	1.075801	6.11%	7.58%

Table 14–Profits Continuous Improvement and Discontinuous Improvement

discontinuous quality improvement cases there is a greater profit advantage in the discontinuous case despite the fact that the terminal quality is marginally superior in the continuous case. This may be attributed to the large jump in sales seen after the discontinuous quality improvement that is not seen in the continuous case See Figure 19 and Figure 20. In the continuous case the sales for competitor one eventually exceed that of competitor two, specifically at time mark 2.6, but the increase is gradual so the number of units influencing sales in the market is low initially. In the case of the discontinuous improvement the number of units influencing sales is large right away resulting in a boost to competitor one via the diffusion element.

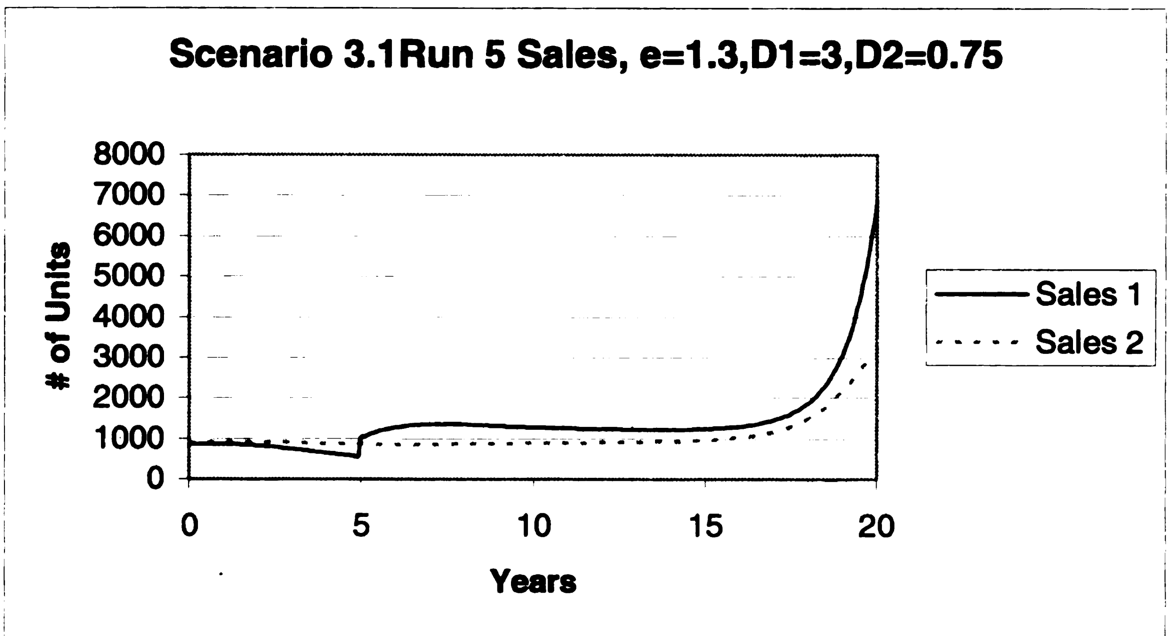


Figure 19 – Sales Discontinuous Quality

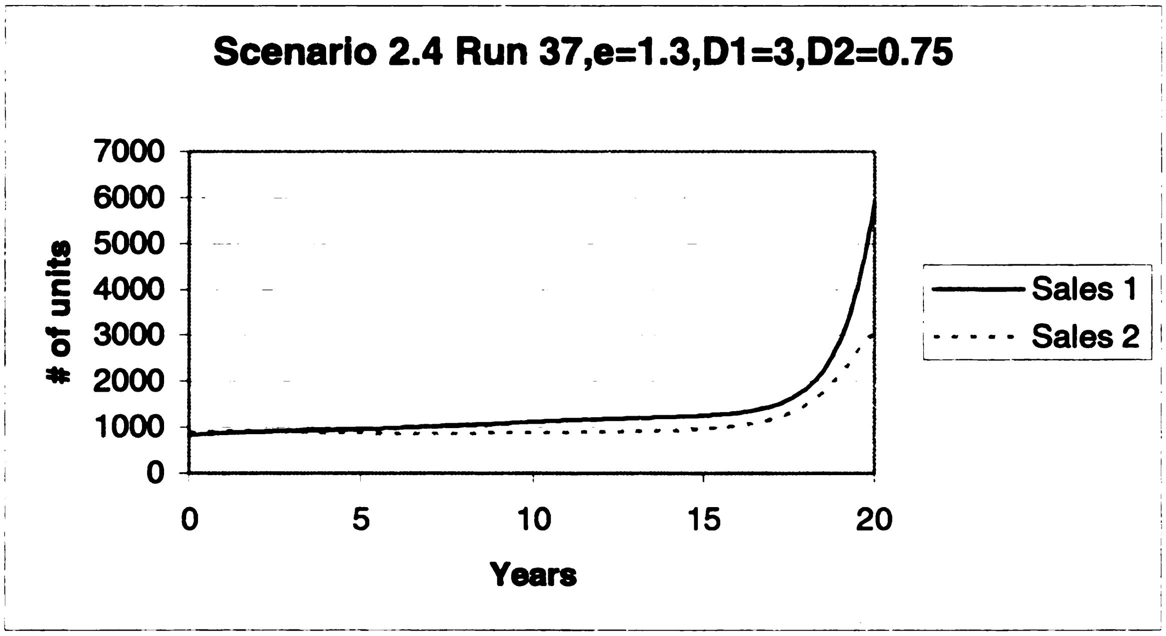


Figure 20– Sales Continuous Quality

Scenarios 3.1-3.2

The next two scenarios add advertising into the analysis of discontinuous quality. In scenario 3.1 the firm introducing the discontinuous quality improvement advertises aggressively during the entire time period. The second firm makes no advertising efforts. This represents the case where a firm attempts to develop market share in advance of the improvements it is going to introduce and continues to support the improvement with advertising efforts for the entire time horizon. Its competitor remains passive during the entire period. The conditions are the same as in scenario 3.0. The quality profile for competitor one begins at 0.5 continues smoothly until year five and then improves by 0.25. It then continues smoothly to a value of 0.85. The quality profile for the second competitor moves from 0.5 to 0.6. Advertising is as described above. Two different elasticity's are tested, 0.7 and 1.3. Two different unit lives are considered 10 and 3 years and the length of time that units in the marketplace continue to influence sales are 75% and 25% of these times. The terminal time horizon is 20 years. The results are seen in Figure 148-Figure 163 Appendix 3.

The price trajectories are similar in nature to those seen in scenario 3.0 where no advertising is present. Advertising performed in a similar fashion to the cases where advertising was present with continuous quality improvement. In all cases it added profits when used to support firm one's quality strategy and in all cases when used as a tool to attempt to retard profits by competitor two it did reduce the net increase in profits realized by the firm pursuing a quality improvement program. See Table 15. The increase or decrease in total profit was generally not significant when comparing the discontinuous quality improvement cases with those of the continuous cases. See Table 16. All maximum and minimum contributions occurred under the same environmental conditions in the discontinuous cases as in the continuous cases. This suggests that advertising is not sensitive to the type of quality improvement policy pursued by the firm. It is as effective in the discontinuous case of quality improvement as it is in the case of continuous quality improvement.

AD Ratio	Conditions	Profits 1	Profits 2	Diff
0.0/0.0	e=0.7,D1=3,D2=0.75	1.337	1.000	-
0.0/0.0	e=0.7,D1=3,D2=2.25	1.123	1.000	-
0.0/0.0	e=0.7,D1=10,D2=2.5	1.206	1.000	-
0.0/0.0	e=0.7,D1=10,D2=7.5	1.141	1.000	-
0.0/0.0	e=1.3,D1=3,D2=0.75	1.375	1.000	-
0.0/0.0	e=1.3,D1=3,D2=2.25	1.133	1.000	-
0.0/0.0	e=1.3,D1=10,D2=2.5	1.150	1.000	-
0.0/0.0	e=1.3,D1=10,D2=7.5	1.076	1.000	-
3.5/0.0	e=0.7,D1=3,D2=0.75	1.355	1.000	1.73%
3.5/0.0	e=0.7,D1=3,D2=2.25	1.133	1.000	0.94%
3.5/0.0	e=0.7,D1=10,D2=2.5	1.227	1.000	2.11%
3.5/0.0	e=0.7,D1=10,D2=7.5	1.160	1.000	1.87%
3.5/0.0	e=1.3,D1=3,D2=0.75	1.394	1.000	1.98%
3.5/0.0	e=1.3,D1=3,D2=2.25	1.144	1.000	1.11%
3.5/0.0	e=1.3,D1=10,D2=2.5	1.169	1.000	1.96%
3.5/0.0	e=1.3,D1=10,D2=7.5	1.091	1.000	1.51%
0.0/3.5	e=0.7,D1=3,D2=0.75	1.313	1.000	-2.40%
0.0/3.5	e=0.7,D1=3,D2=2.25	1.112	1.000	-1.13%
0.0/3.5	e=0.7,D1=10,D2=2.5	1.181	1.000	-2.45%
0.0/3.5	e=0.7,D1=10,D2=7.5	1.121	1.000	-2.05%
0.0/3.5	e=1.3,D1=3,D2=0.75	1.348	1.000	-2.64%
0.0/3.5	e=1.3,D1=3,D2=2.25	1.119	1.000	-1.38%
0.0/3.5	e=1.3,D1=10,D2=2.5	1.127	1.000	-2.23%
0.0/3.5	e=1.3,D1=10,D2=7.5	1.058	1.000	-1.76%

Table 15 – Profit Difference from Advertising

AD RATIO	CONDITIONS	DISC. q	CONT. q	DIFF
0.0/0.0	e=0.7,D1=3,D2=0.75	1.337	1.277	0.0600
0.0/0.0	e=0.7,D1=3,D2=2.25	1.123	1.101	0.0220
0.0/0.0	e=0.7,D1=10,D2=2.5	1.206	1.171	0.0350
0.0/0.0	e=0.7,D1=10,D2=7.5	1.141	1.119	0.0220
0.0/0.0	e=1.3,D1=3,D2=0.75	1.375	1.31	0.0650
0.0/0.0	e=1.3,D1=3,D2=2.25	1.133	1.114	0.0190
0.0/0.0	e=1.3,D1=10,D2=2.5	1.15	1.132	0.0180
0.0/0.0	e=1.3,D1=10,D2=7.5	1.076	1.061	0.0150
3.5/0.0	e=0.7,D1=3,D2=0.75	1.355	1.294	0.0610
3.5/0.0	e=0.7,D1=3,D2=2.25	1.133	1.111	0.0220
3.5/0.0	e=0.7,D1=10,D2=2.5	1.227	1.192	0.0350
3.5/0.0	e=0.7,D1=10,D2=7.5	1.16	1.137	0.0230
3.5/0.0	e=1.3,D1=3,D2=0.75	1.394	1.33	0.0640
3.5/0.0	e=1.3,D1=3,D2=2.25	1.144	1.125	0.0190
3.5/0.0	e=1.3,D1=10,D2=2.5	1.169	1.152	0.0170
3.5/0.0	e=1.3,D1=10,D2=7.5	1.091	1.077	0.0140
0.0/3.5	e=0.7,D1=3,D2=0.75	1.313	1.254	0.0590
0.0/3.5	e=0.7,D1=3,D2=2.25	1.112	1.09	0.0220
0.0/3.5	e=0.7,D1=10,D2=2.5	1.181	1.148	0.0330
0.0/3.5	e=0.7,D1=10,D2=7.5	1.121	1.099	0.0220
0.0/3.5	e=1.3,D1=3,D2=0.75	1.348	1.285	0.0630
0.0/3.5	e=1.3,D1=3,D2=2.25	1.119	1.1	0.0190
0.0/3.5	e=1.3,D1=10,D2=2.5	1.127	1.11	0.0170
0.0/3.5	e=1.3,D1=10,D2=7.5	1.058	1.044	0.0140

Table 16 - Difference Cont. Case vs. Discontinuous

Scenario 3.3

The runs constituting scenario 3.3 consider what happens when the second company initiates a discontinuous quality improvement program of its own at a later date then the first company. In this scenario the advertising efforts for both companies are set to zero. The quality profile for the first company is the same as in scenarios 3.0-3.2. It begins at 0.5 improves steadily to year five where it increases by 0.25 and then continues to increase at a steady rate until year 20 with a terminal value of 0.85. Firm two starts at 0.5 and improves steadily until year 10 at which time it improves by 0.25 and then it continues to improve at a steady rate until year 20. Two different elasticity's are tested, 0.7 and 1.3. Two different unit lives are considered 10 and 3 years and the length of time that units in the marketplace continue to influence sales are 75% and 25% of D1. See Figure 164-Figure 171 Appendix3.

The price curves show that the ability to increase price mirrors each other under all conditions. The first firm gains some profit advantage when the unit life is short relative to when the unit life is long. See Table 17. Furthermore, it gains a somewhat greater advantage when the influence on sales by existing units is short. This advantage is reduced or disappears when working in an elastic environment. Short unit life spans allows for the introduction of higher quality units into the market. The short influence periods allows for the newer higher quality units to influence sales quicker and with larger numbers. It is not surprising that when the percent change in demand is less then the percent change in price the firm with the early price advantage is not able to create a greater profit margin via an increase in sales due to a reduction in price.

RUN #	CONDITIONS	FIRM 1	FIRM 2	ADVANTAGE
25	e=0.7,D1=3,D2=0.75	1.089	1	8.86%
26	e=0.7,D1=3,D2=2.25	1.040	1	3.98%
27	e=0.7,D1=10,D2=2.5	1.061	1	6.05%
28	e=0.7,D1=10,D2=7.5	1.048	1	4.76%
29	e=1.3,D1=3,D2=0.75	1.075	1	7.48%
30	e=1.3,D1=3,D2=2.25	1.018	1	1.79%
31	e=1.3,D1=10,D2=2.5	1.001	1	0.10%
32	e=1.3,D1=10,D2=7.5	0.994	1	-0.58%

Table 17 – Profit Advantage with 2 Discontinuous
q Improvements

Scenario 3.4

The runs in scenario 3.4 use advertising as a purely tactical tool. The first firm with the discontinuous increase in quality only begins advertising when the quality improvement is introduced. Firm one begins an advertising policy that uses 3.5% of its revenues in the same time period that it introduced the discontinuous quality improvement. All other conditions are the same as for scenario 3.3. The resulting price curves may be seen in Figure 172-Figure 179.

The price curves show no significant changes from scenario 3.3. There is a difference in the profit generated under the different conditions. The difference between using advertising aggressively when the discontinuous quality improvement for the first company is put into place as a deterrent to the future improvement in the second company and using no advertising at any time is show in Table 18. These values are normalized to the profits generated by the second competitor.

CONDITIONS	AD=0.0%	AD=3.58%	ADV.0%	ADV.3.5%	DIFF.
e=0.7,D1=3,D2=0.75	1.089	1.100	8.86%	9.98%	1.12%
e=0.7,D1=3,D2=2.25	1.040	1.046	3.98%	4.59%	0.61%
e=0.7,D1=10,D2=2.5	1.061	1.076	6.05%	7.62%	1.57%
e=0.7,D1=10,D2=7.5	1.048	1.062	4.76%	6.19%	1.43%
e=1.3,D1=3,D2=0.75	1.075	1.087	7.48%	8.68%	1.20%
e=1.3,D1=3,D2=2.25	1.018	1.025	1.79%	2.50%	0.71%
e=1.3,D1=10,D2=2.5	1.001	1.016	0.10%	1.57%	1.48%
e=1.3,D1=10,D2=7.5	0.994	1.007	-0.58%	0.66%	1.24%

Table 18 – Advantage from Advertising Scenario
3.4

Minor increases in profits for firm one relative to firm two are seen in all cases. The amount of these increases changes depending on the unit life, the length of time the units existing in the market continue to influence sales and on the price electricity. The least improvement is seen under short unit life spans, relatively long unit influence on sales and inelastic conditions. The greatest improvement is seen under long unit life spans, short influence time and inelastic conditions.

CHAPTER 5

Conclusions and Contributions

Contributions

There are three significant areas of understanding to which this work contributes. First, is the use of quality as a strategic lever in a competitive environment. Second, is how advertising influences quality as a strategic lever in a competitive environment. Third, is how a discontinuous quality change alters the use of quality as a strategic lever under competitive conditions while being influenced by advertising. Each of theses topics has been considered piecemeal before but they have not been considered together so that the interactions may be examined.

Quality influences on dynamic pricing in a duopoly

When considering how to effectively use an aggressive quality policy, one where the product quality increases faster than the competition's quality, as a strategic tool there are three factors that this dissertation examines which a manager should incorporate into his decision. These factors are the price elasticity, the length of time that an individual unit will exist in the market relative to the total life of the product line and the length of time during which a unit will continue to influence sales once it has entered the market i.e., quality perception.

Using elasticity as an environmental factor two by two grids may be developed to summarize these choices. The first of these two grids is depicted in Figure 140. See also Table

7. Under lower price elasticity the greatest relative increases in profit may be seen in quadrant A.

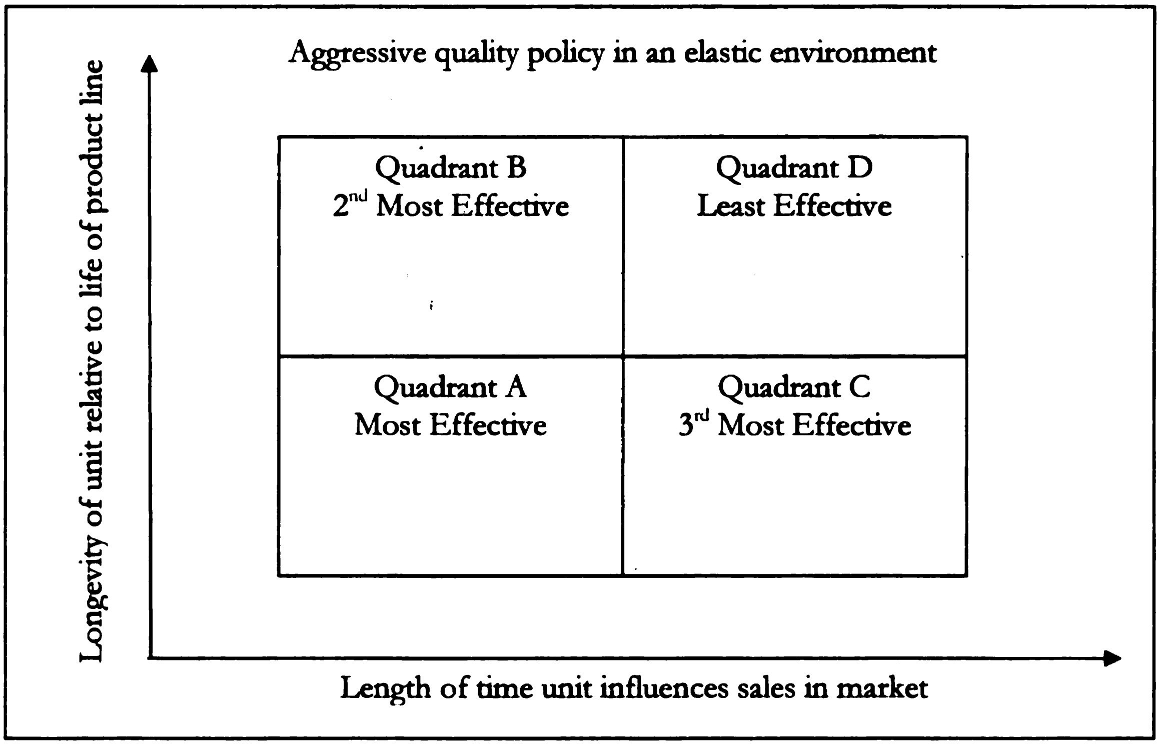


Figure 21 – Profit Advantage when Price elasticity is higher

The conditions in this quadrant are thus the life of the unit relative to the life of the product line is the shortest and the length of time that the unit in the market influences sales is the shortest. The least profit increase over the competitor derived from an aggressive quality strategy are when the life of the unit is long and the length of time the unit influences sales is also long. This is not to suggest that a manager would not want to pursue the added profits that could be obtained from pursuing an aggressive quality policy under the least effective conditions. Profit is profit under any conditions. It is only to suggest that the greatest returns from such a strategy will be realized under the conditions existing in quadrant A where the quality strategy is most effective.

Given environmental conditions where the price elasticity is lower there is a somewhat different set of conditions that will maximize the profits a company will see relative to its competitor. See Figure 141. See also Table 7. In this environment there is a change in the

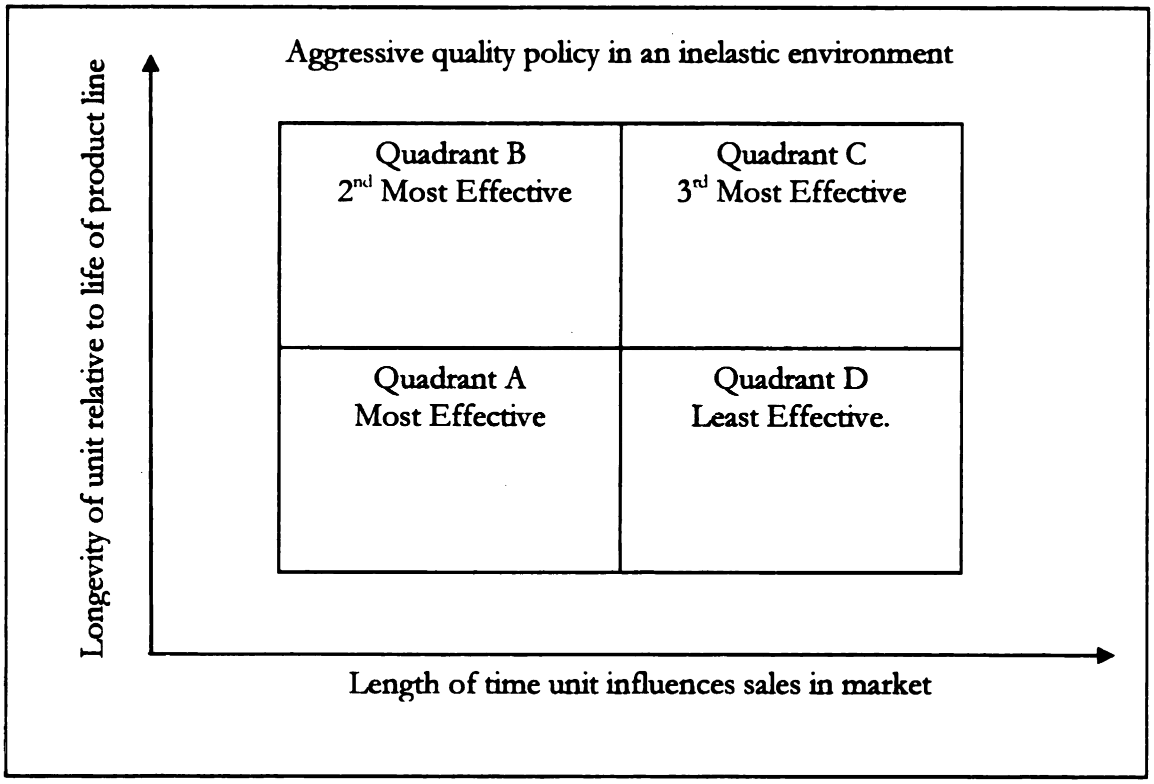


Figure 22 – Profit Advantage Inelastic Demand

position of the least improvement in profitability, quadrant D; it shifts to the bottom right position. The conditions for this are a shorter unit life span and a large percentage of time when existing units in the market continue to influence sales. Summarizing, a firm pursuing an aggressive quality improvement strategy relative to its competitor can expect the greatest improvements in either elastic or inelastic conditions when the unit life is large relative to the amount of time existing units in the market influence its sales. However, when low price elasticity exists it can expect a larger profit relative to its competitor if the life of the unit is shorter when there is a long impact on sales by individual units. Conversely, when high price elasticity exists the firm can expect a larger profit relative to its competitor if the life of the unit is long when there is a long impact on sales by individual units. The interaction between durability and quality perception tends to be high as a result market saturation somewhat offsets this effect.

It is also interesting to note that the initial conditions have an impact on the price trajectory over the entire life of the product line. If there is an initial price difference the fact that there is a substitutable good in the market will force the firm with the higher price to lower its price trajectory below that of the firm with the initial price advantage so as to maximize its profits. While not surprising in and of itself this does suggest that there are some characteristic of a complex dynamic system present in the price-quality-competition relationship. Sensitivity to initial conditions is one of the three conditions describing a formally defined chaotic system.

Advertising and Quality influences on dynamic pricing in a duopoly

When advertising is added as a moderating factor to the price quality relationship as it influences maximized profits there are two additional conditions added to the analysis. In addition to price demand elasticity, the life of the unit relative to the life of the product line and the length of time the individual unit in the market influences sales, advertising to support an aggressive quality policy or as a deterrent to sales by the firm not pursuing the aggressive quality policy are also considered. These are summarized in Figures 142 to 145. See also Table 9.

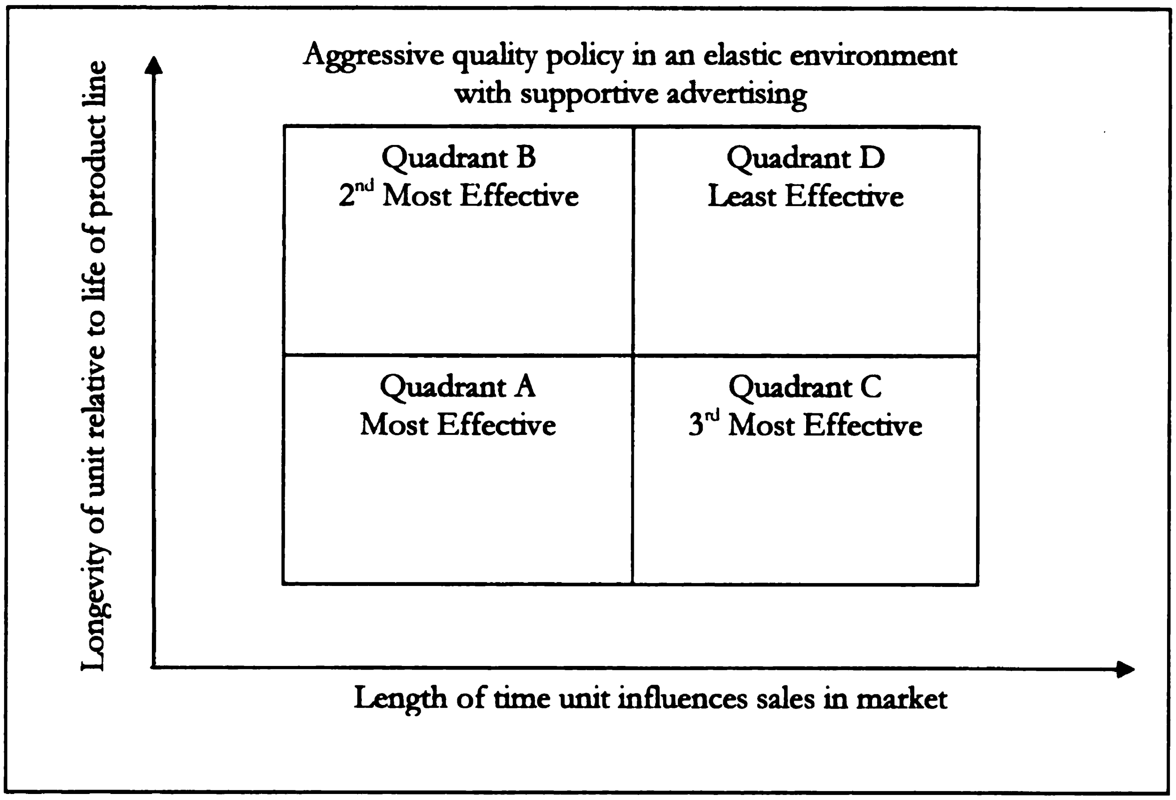


Figure 23 – Advertising Impact Supporting Quality
(Elastic Demand)

As can been seen in Figures 142 and 143 the most return on an advertising policy supporting an aggressive advertising policy may be realized when the influence of the individual unit is short relative to the life of that unit. A firm can expect that the least return on an advertising policy supporting an aggressive advertising policy relative to increased profits when compared with its competitor will be when the units in the market have the longest influence on sales. Furthermore, as in the case with no advertising, the effectiveness will change under differing elasticity's. Under elastic conditions the least effectiveness will be with units that have long life spans and long market influences. Under inelastic conditions the least effectiveness will be with units that have short life spans and long market influences.

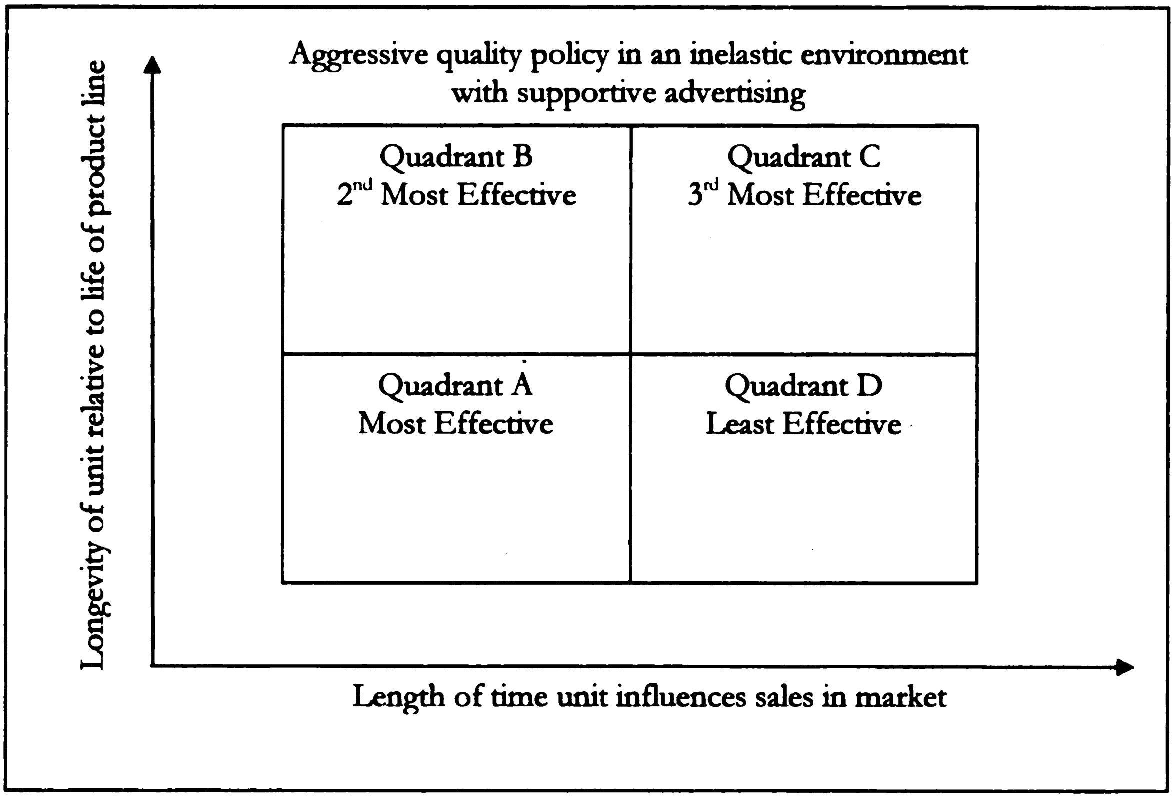


Figure 24 – Advertising Impact Supporting Quality
Inelastic Demand

These results differ somewhat when a firm uses advertising to counter to an aggressive quality policy. See Figure 144 and 145. See also Table 9. In the low price elasticity case the results are the same when advertising is used as a supportive tactic to quality improvement. In contrast when price elasticity is high the most effective use of advertising occurs when the life of the individual unit is the longest and the influence of the unit on sales in the market place is shortest. This suggests that the firm that is choosing not to compete on quality might reduce the profit advantage seen by the firm competing on quality by heavily advertising under these conditions. See Figure 145.

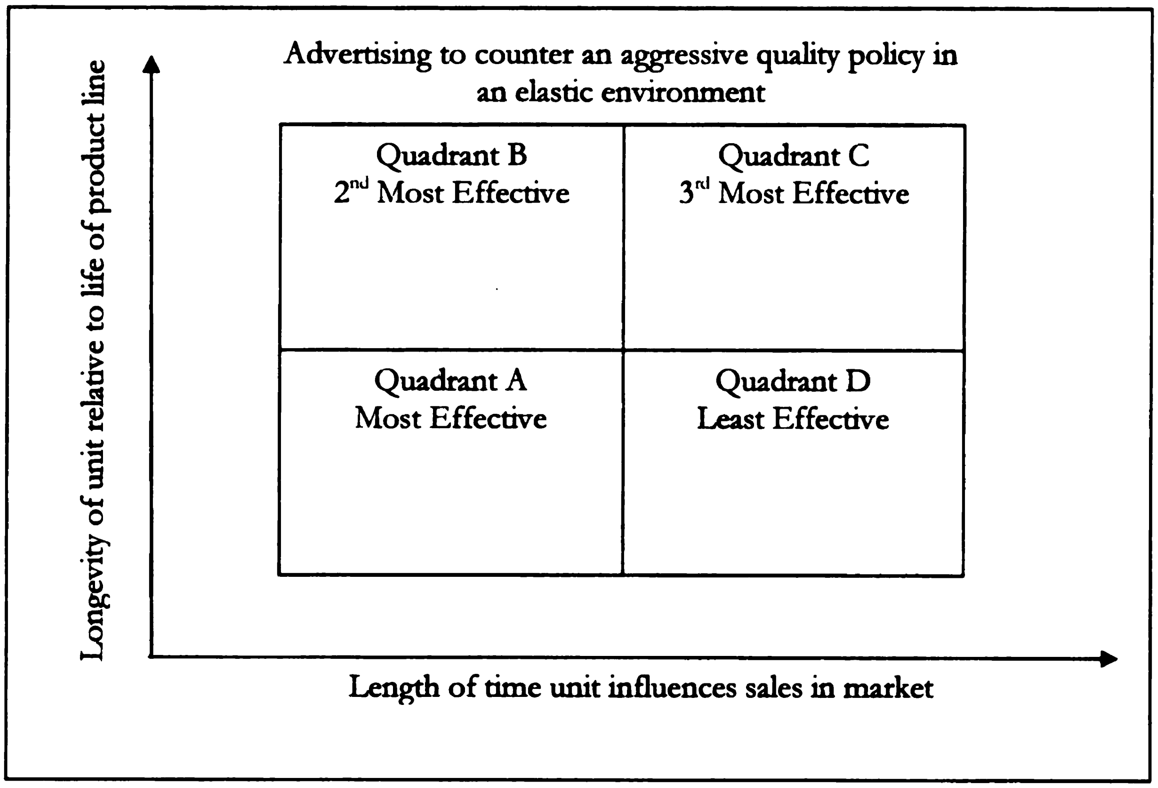


Figure 25 – Counter Advertising Elastic Demand

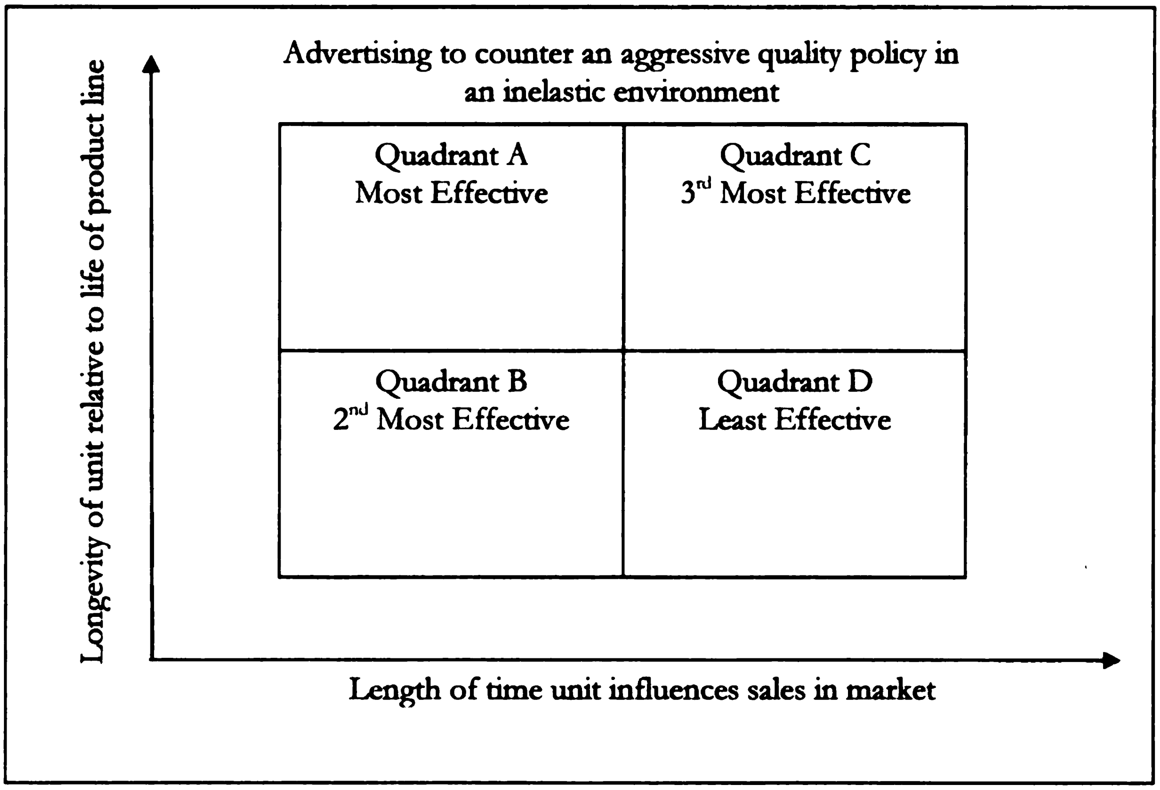


Figure 26 – Counter Advertising Inelastic Demand

Advertising and Discontinuous Quality influences in a duopoly

In the examination of discontinuous quality improvements it was found that a large one time improvement did not provide any significant increase in profitability over the case where quality was improved continuously over time. This is not surprising. Kaizan, the Japanese philosophy of making small improvements continuously, has long been accepted as a desirable process in TQM. It was found that advertising assisted the profit differential in the same manner when it was used in the discontinuous quality case as it did when it was used in the continuous quality case. See Figures 146 and 147. See also Tables 14 and 15

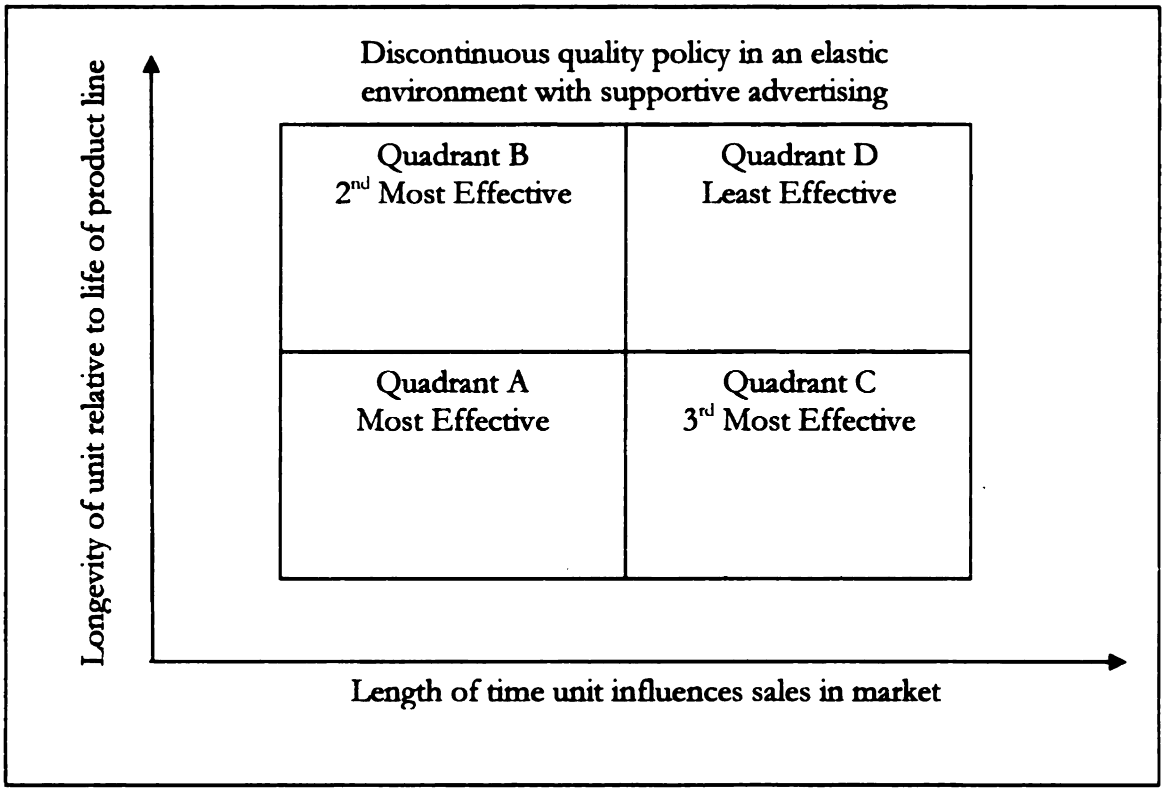


Figure 27 – Discontinuous Quality and Advertising
Elastic Demand

Neither were any differences in the use of advertising as a counter tool to a discontinuous quality improvement seen relative to its use when countering a continuous quality improvement policy. See Figures 147 and 148. See also Table 15.

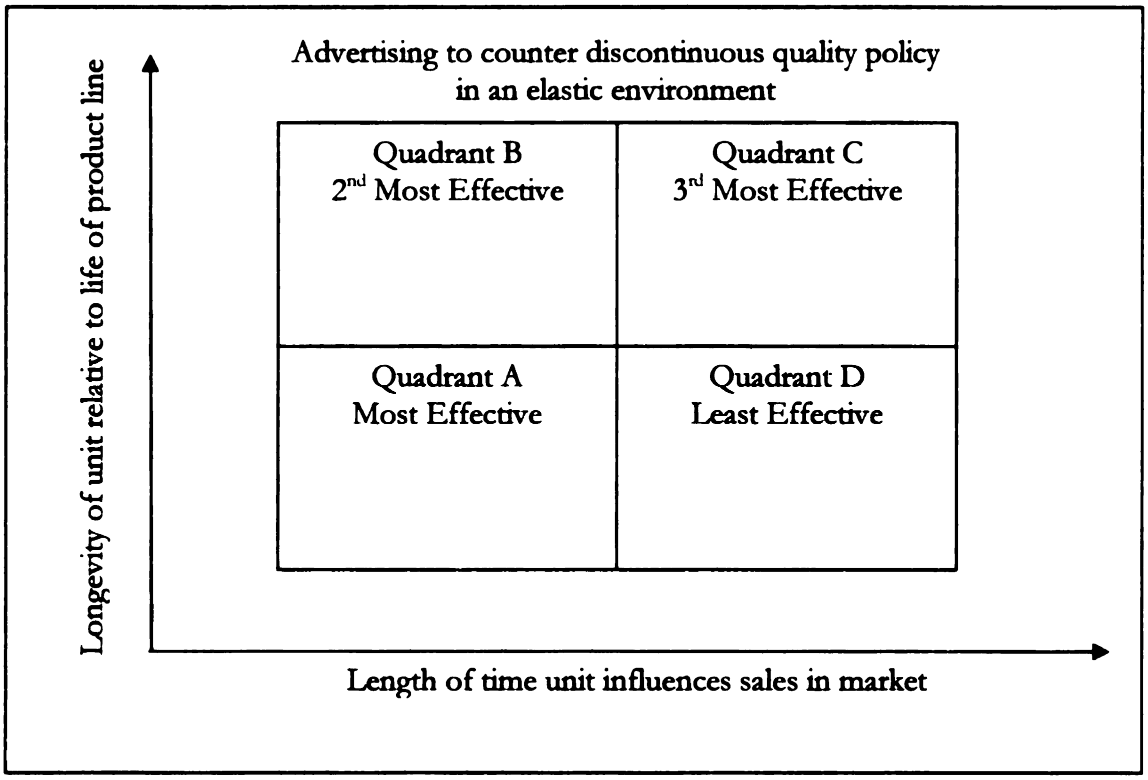


Figure 28 – Advertising to Counter Discontinuous
Quality Elastic Demand

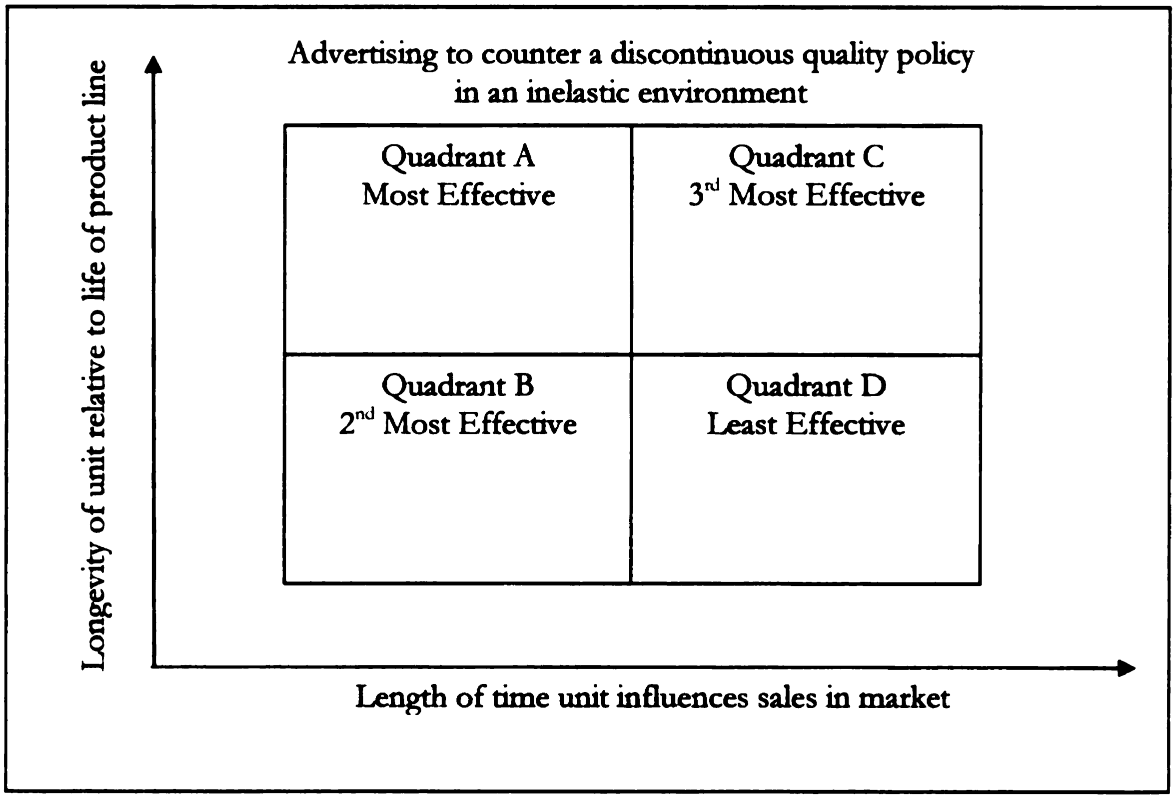


Figure 29 - Advertising to Counter Discontinuous Quality Inelastic Demand

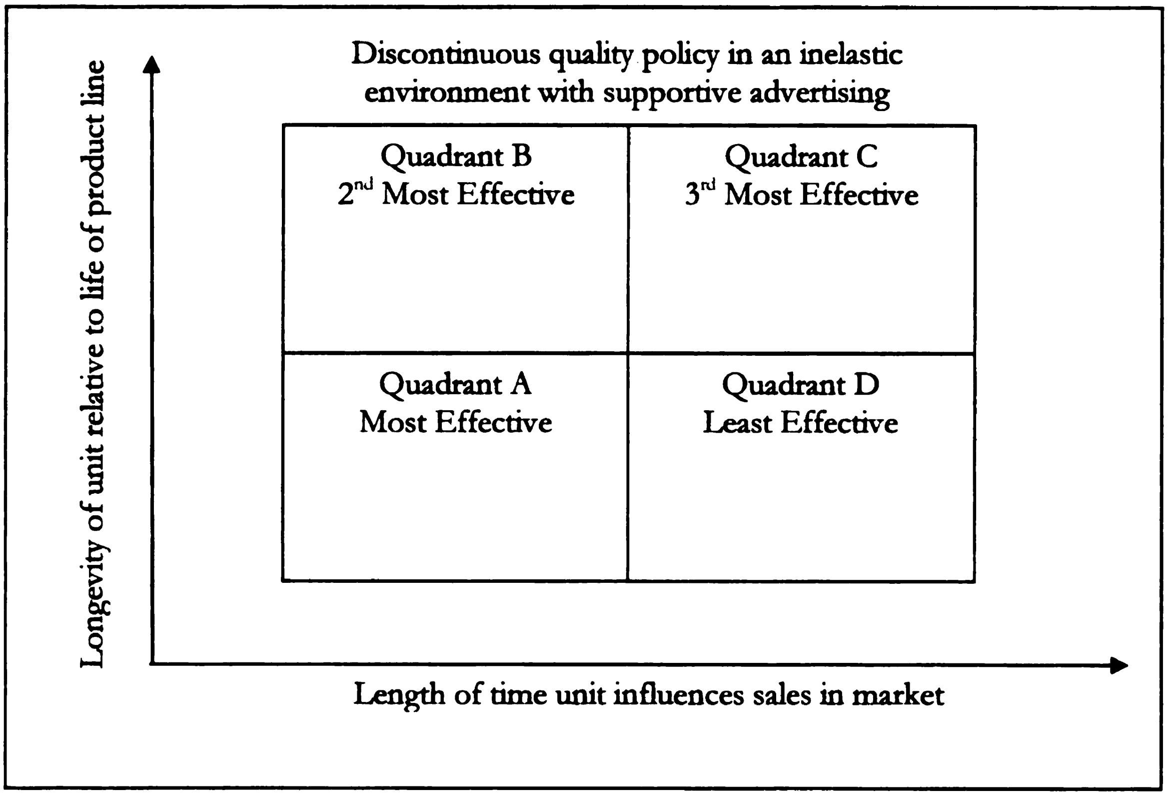


Figure 30 - Discontinuous Quality and Advertising
Inelastic Demand

Strategic Implications

In order to properly asses the strategic implications of the results of this dissertation it is necessary to consider several relevant pieces of information. First is the sales response over time for the two models used to develop the model in this dissertation, the NGM model and the Erickson model for competitive advertising and the model developed here in. Figure 31 shows the typical sales distribution over time for the model developed in this dissertation. Figure 32 shows the typical sales distribution over time of the NGM model and Figure 33 shows the Erickson competitive advertising modes showing sales vs. time.

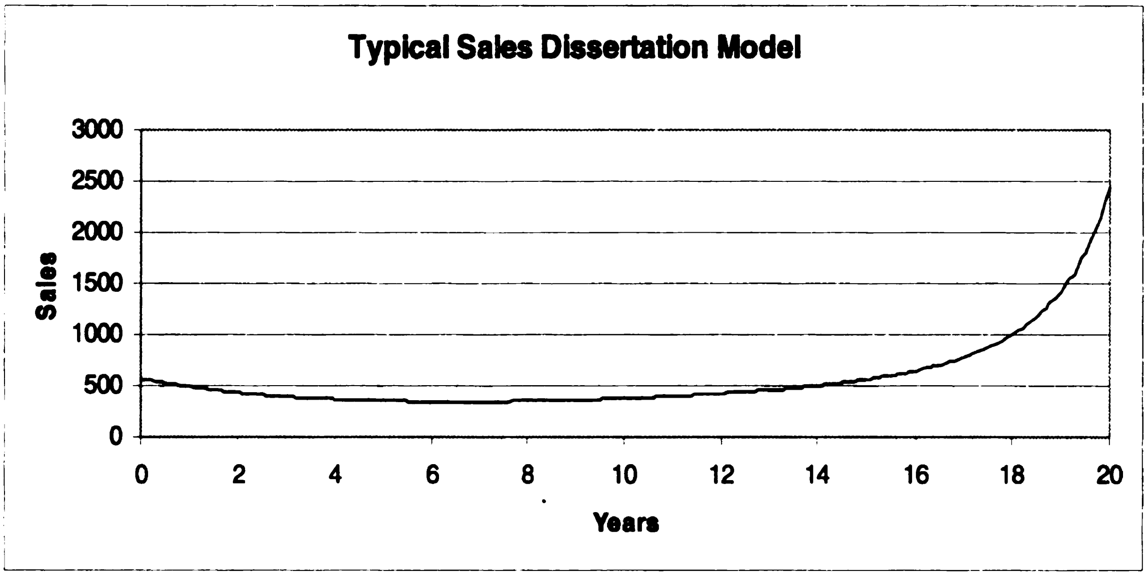


Figure 31 – Typical sales for dissertation model

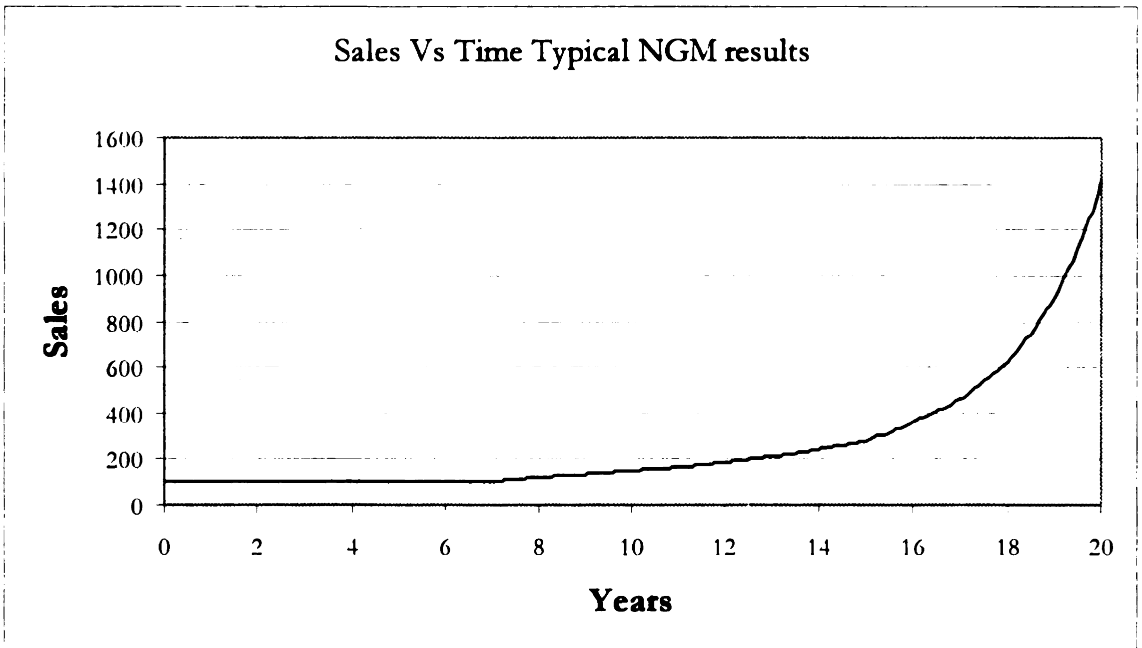


Figure 32 – Typical NGM sales distribution

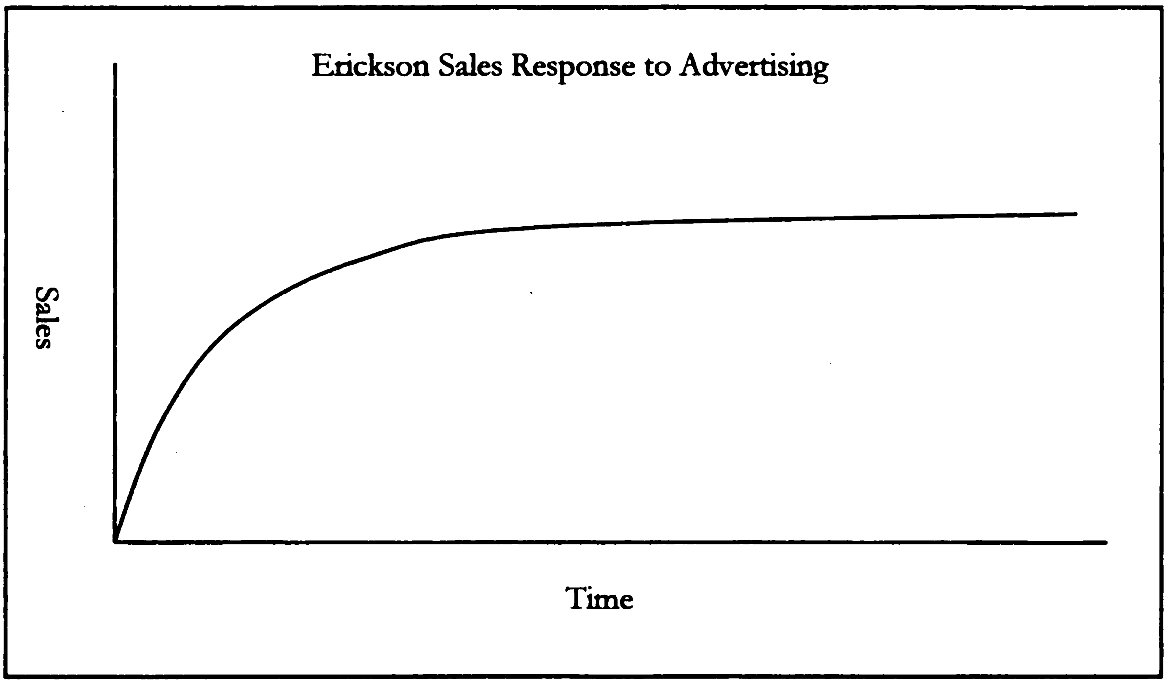


Figure 33 – Typical Erickson Sales Response over
Time to Advertising

In the case of the Erickson model sales increase initially and eventual reach a steady state. This is because the Erickson model incorporates neither dynamic pricing nor improving product quality into the sales relationship. Both of these factors influence sales above and beyond the influence that advertising imparts to sales alone. In the case of the NGM model sales remain relative steady for a period of time and then increase radically as the price is reduced so the firm may maximize profits. In the case of the model developed in this dissertation the sales initially decline a small amount and then increase as the price declines. The initial decline in sales represents the competitive situation created by a substitutable product in a competitive environment. This clearly indicates that a manager should not attempt to maintain or increase prices early in the life cycle of a product line if they intend to maximize the total profits for the product line over its life. Of more interest to a manager are the implications a comparison of the price trajectories of the NGM model and the model developed in this work product. The price trajectories are depicted in Figure 34 and Figure 35. Note that the Erickson model did not incorporate pricing into the sales model and is therefore not included in this analysis.

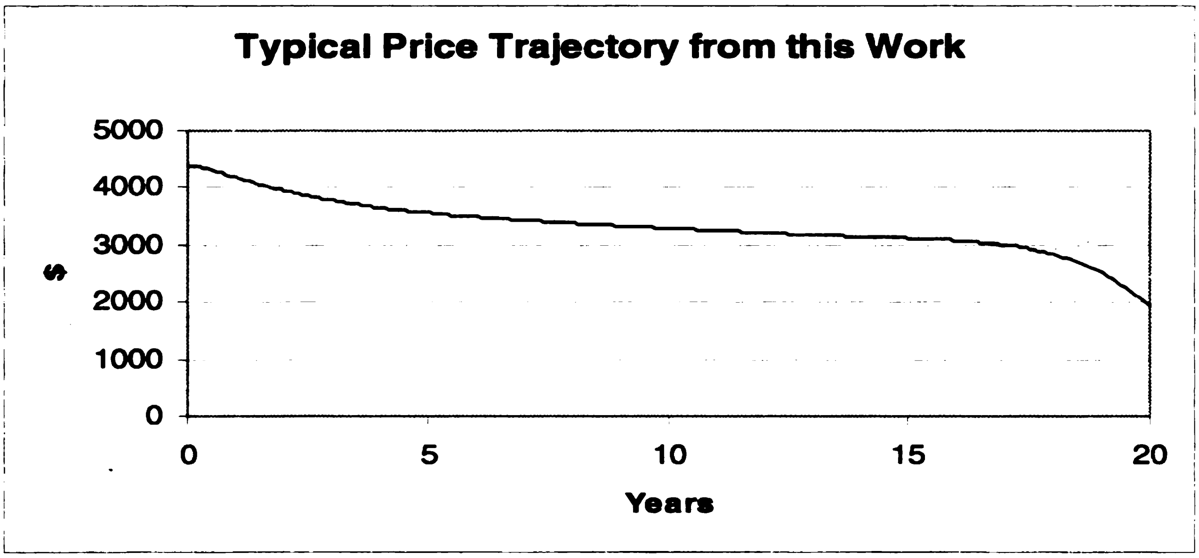


Figure 34 – Price Trajectory from this Work

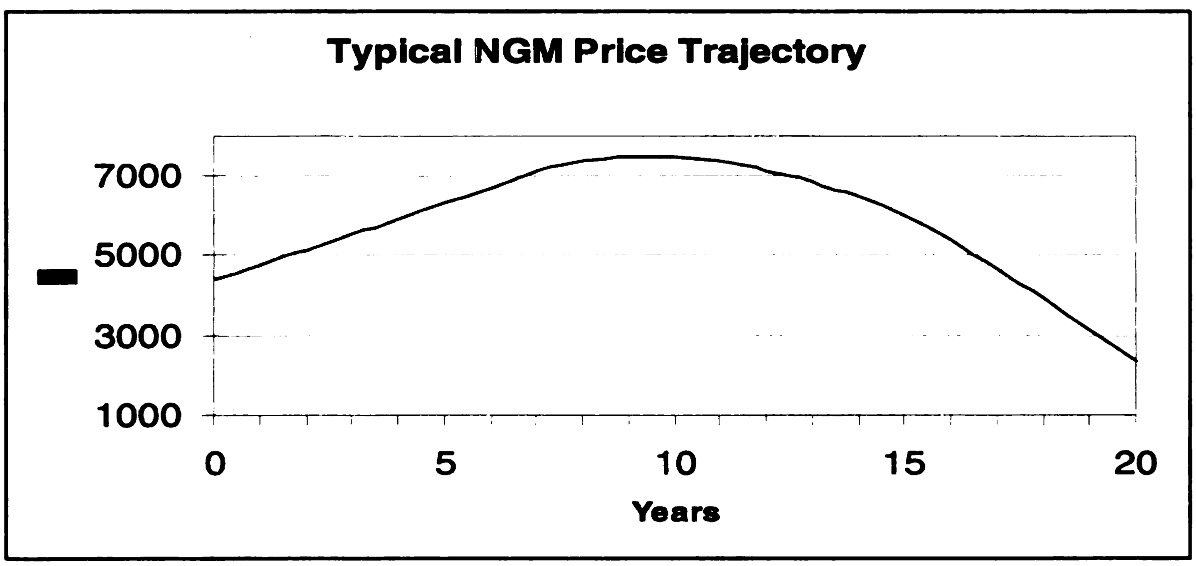


Figure 35 – Typical NGM Price Trajectory

In the case of the NGM model where competition is not explicitly modeled the price trajectory increase initially and then declines while quality continuously increases. This suggests that to maximize profits a manager should increase prices during the initial phase of the product life cycle. While a price increase may be interpreted as a signal of quality in accordance with the idea that consumers equate price with quality, see for example (Irandoust 1998 and Rao, 1989 #27), it is not conducive to maximum profitability in a competitive situation. When competition is explicitly incorporated into the model in this dissertation the price trajectory may be seen to decline immediately and it continues down at various rates of change during the entire life of the product. This means that a manager should use the quality diffusion aspects of the market to signal quality to the consumer. This strategy will increase the number of units in the market; enhance the rate of diffusion of the quality information to consumers and increase profits to a greater level than maybe achieved by a short term increase in price. Conceptually this indicates that the connection between price and quality is not robust. The result of the diffusion of quality units into the market dominates the perception that a high price indicates higher levels of quality. This position is supported by the concept that quality and price should not be directly connected in the consumers' perception. See for example (Gerstner 1985; Lichtenstein and Burton 1989; Riesz 1978; Riesz 1979; Sprokes 1977). The concept that consumers will not relay on the price-quality-advertising relationship when information to the contrary is available via alternative mechanisms, such as individual information searches, sce (Milgrom and Roberts 1986a; Milgrom and Roberts 1990; Nelson 1974; Nelson 1970), is reaffirmed by the model developed in this dissertation.

Relative to continuous and discontinuous quality improvements this work indicates that the firm should consider the environment, the useful life expectance of a unit and the length of time that a unit influences consumer purchase decisions when using quality as a strategic lever. When price elasticity is both relatively high and low quality as a strategic lever is most effective when the unit life is relatively short when compared to the life of the product line and when the length of time that the unit influences consumer purchasing decisions is relatively short. Therefore a manager should emphasize discontinuous quality improvements which will make consumers more inclined to replace the individual unit before its functional life has expired. For example, a lawn tractor might have a useful life of ten years and a truly satisfied customer might continue to praise the machine for the majority of that time. If however during that ten year period a new discontinuous improvement is made to the line of lawn tractors, such as the development of a cutting mulching system, that consumer while satisfied will be more inclined to replace that unit before its entire useful life has expired. This is in contrast to incremental improvements that the consumer might not view as sufficiently valuable to justify the expense of early unit replacement. The implication of this conceptually is that research and development expenditures that aim at large changes in quality are potentially beneficial if they reduce the unit life expectancy and the length of time units influence consumer purchasing decisions.

In all cases studied in this work advertising while providing an increase in profitability during the life of the product line it is always dominated by a quality strategy. As a result a manager should consider an advertising policy as a means of assisting a quality strategy or in the case of a manager seeking a means of reducing the profitability advantage of a competitor, as a minor counter to a quality strategy; he should not consider it a replacement for either a continuous or discontinuous quality improvement strategy.

Concluding Remarks

This research has examined optimal pricing for two profit maximizing firms using different advertising and quality policies. An optimal control model utilizing different demand elasticity's, different unit life spans and differing lengths of time during which units existing in the market influenced sales was solved numerically and the results tabulated. Prior to this work a dynamic pricing optimal control model explicitly including competition had not been developed. Prior to this work advertising had not been included in this type of quality-price model. Prior to this work, discontinuous quality improvements had not been explicitly included in this type of quality-price model.

The results reaffirm the importance of quality as a strategic lever and demonstrate under what type of conditions a quality based strategy, continuous or discontinuous, might be most effective in a competitive environment. The results also show under what conditions advertising might be most effectively utilized by a firm's management to increase its profitability over a competitor and thereby increase its share holder value relative to that competitor. New areas of investigation are also suggested by the results. Different levels of advertising effectiveness need to be examined. Different entry times into the market should be considered. Advertising policies other than continuous ones also might be considered.

APPENDICES

Appendix 1

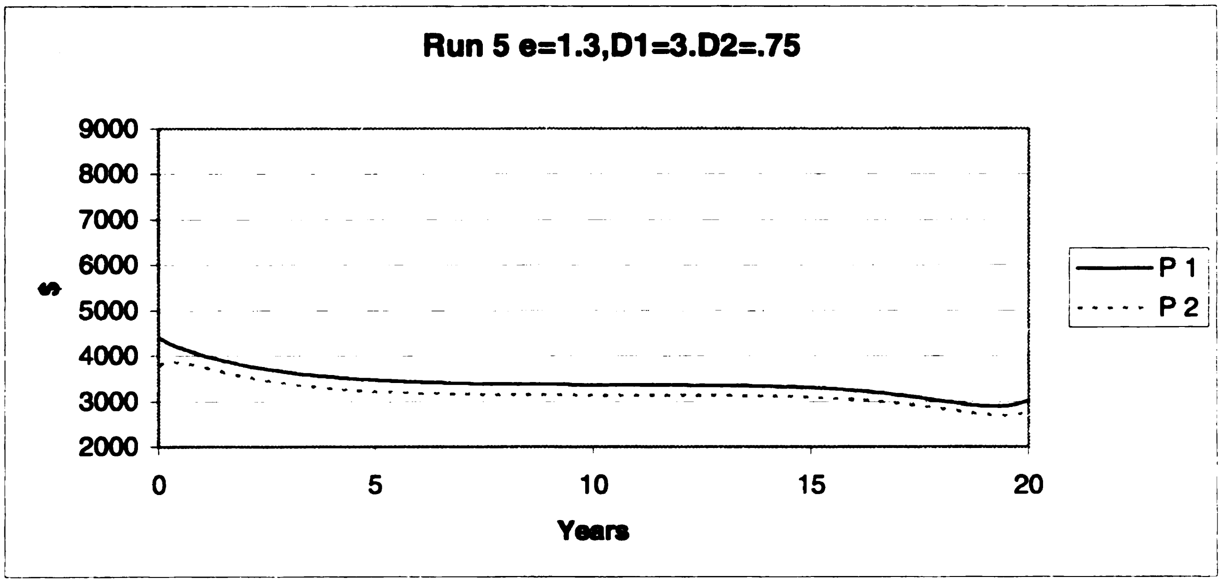


Figure 36 - Run 5 Scenario 1.0

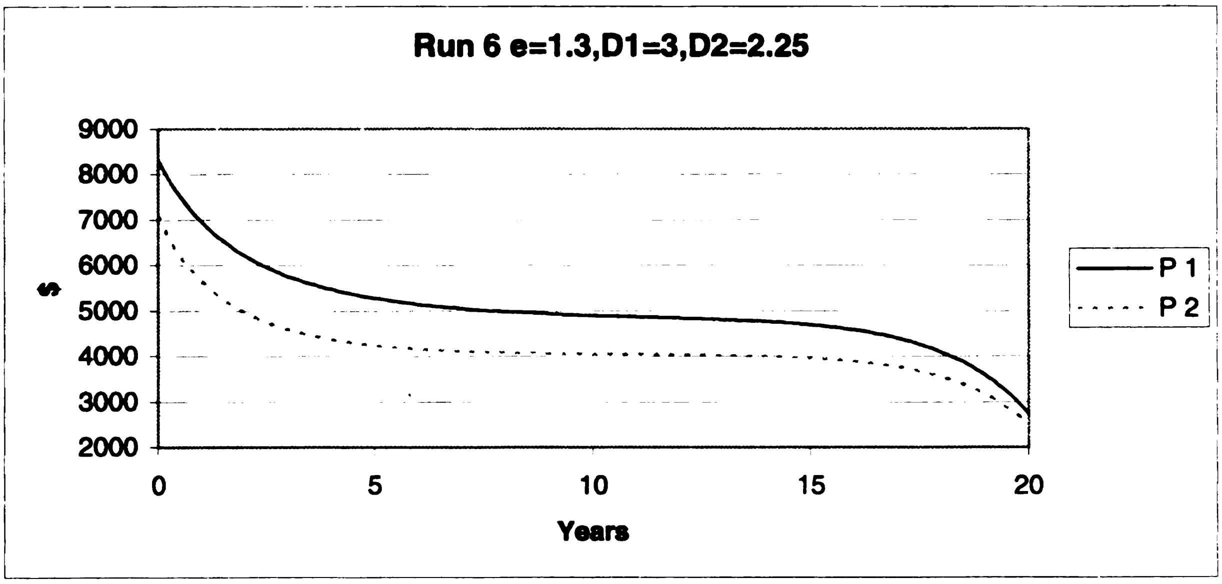


Figure 37 - Run 6 Scenario 1.0

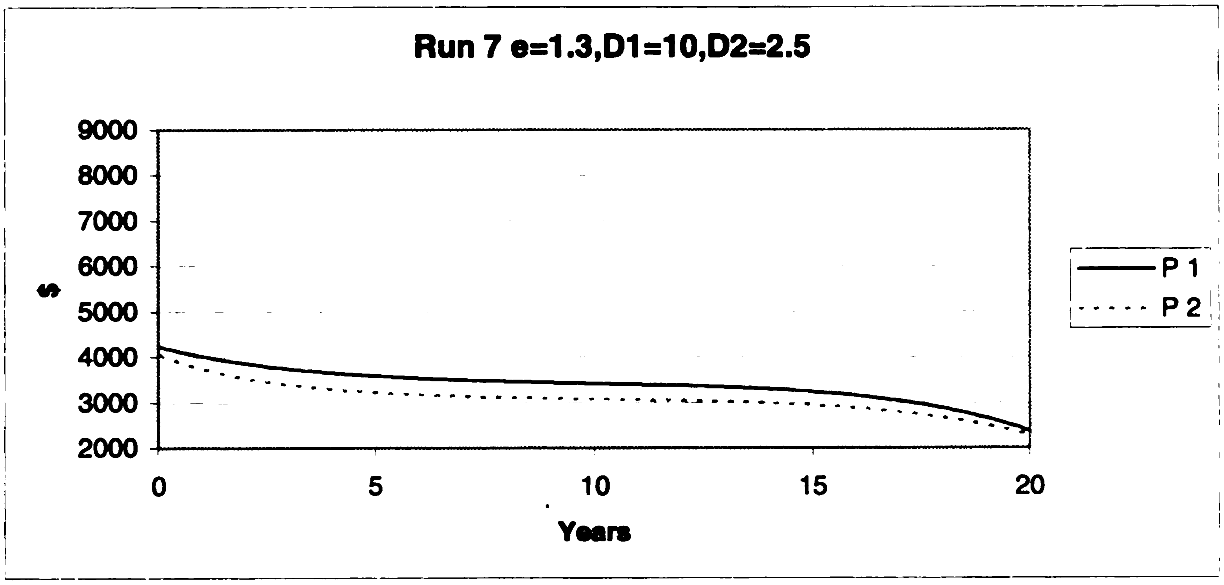


Figure 38- Run 7 Scenario 1.0

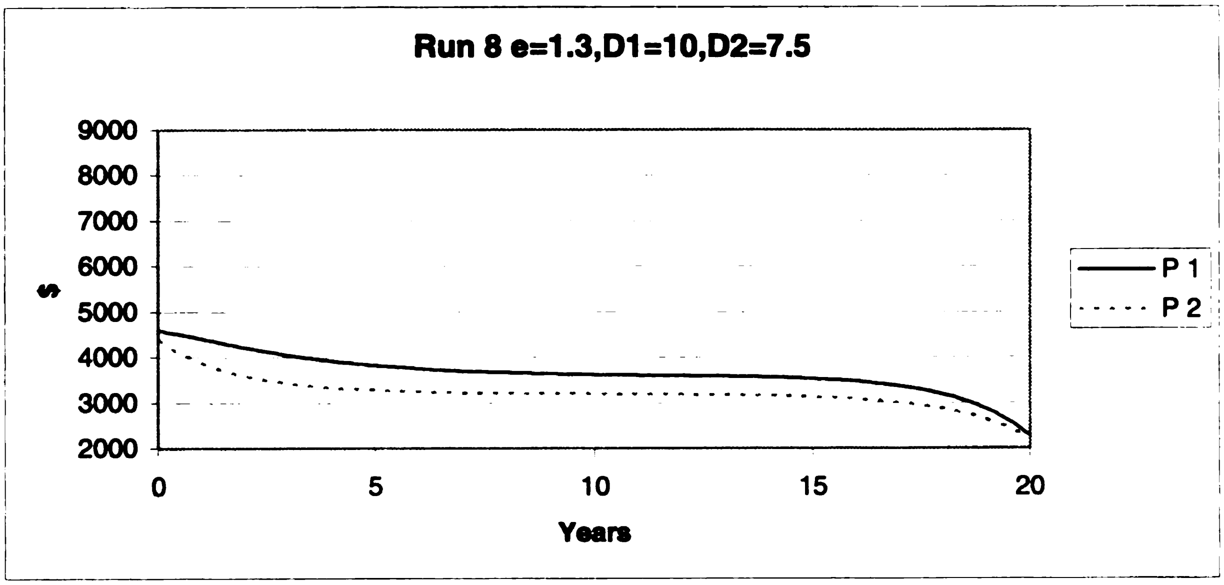


Figure 39 – Run 8 Scenario 1.0

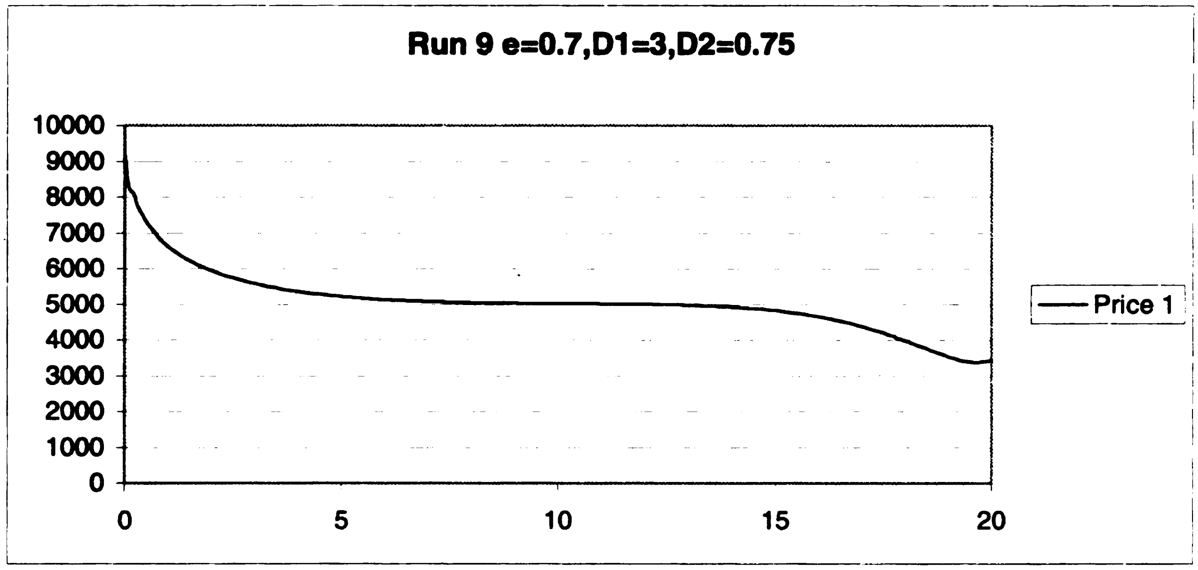


Figure 40 – Run 9 Scenario 1.1

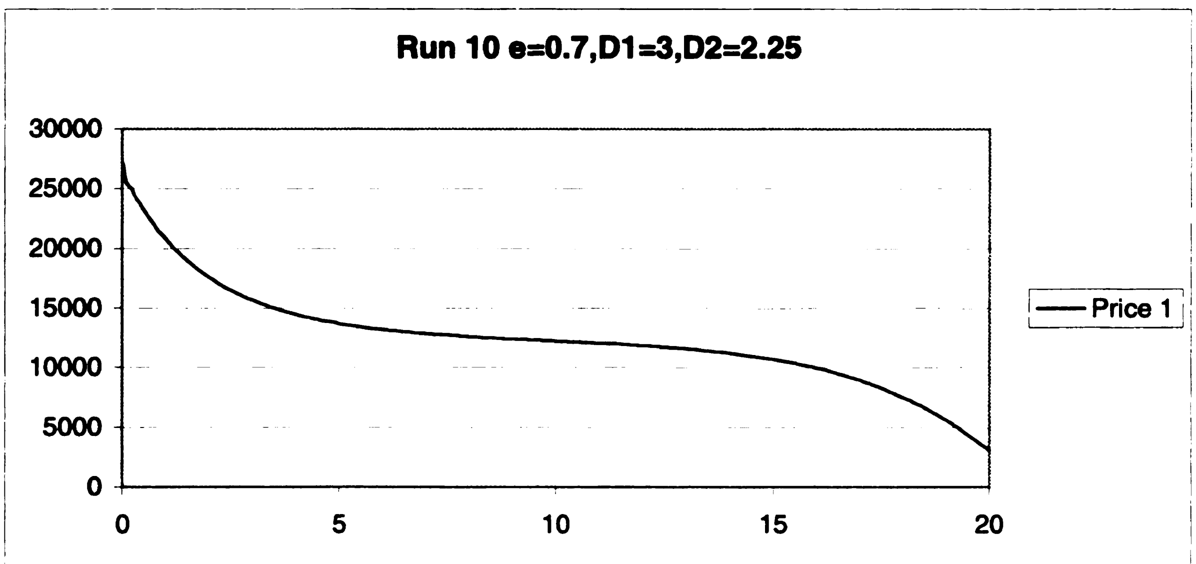


Figure 41 – Run 10 Scenario 1.1

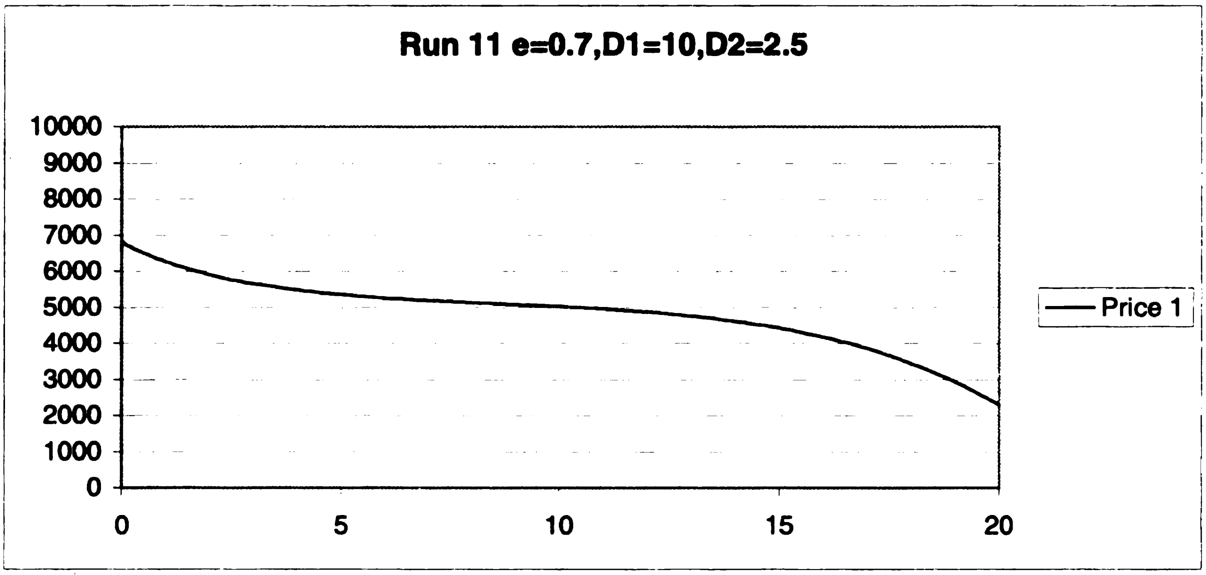


Figure 42– Run 11 Scenario 1.1

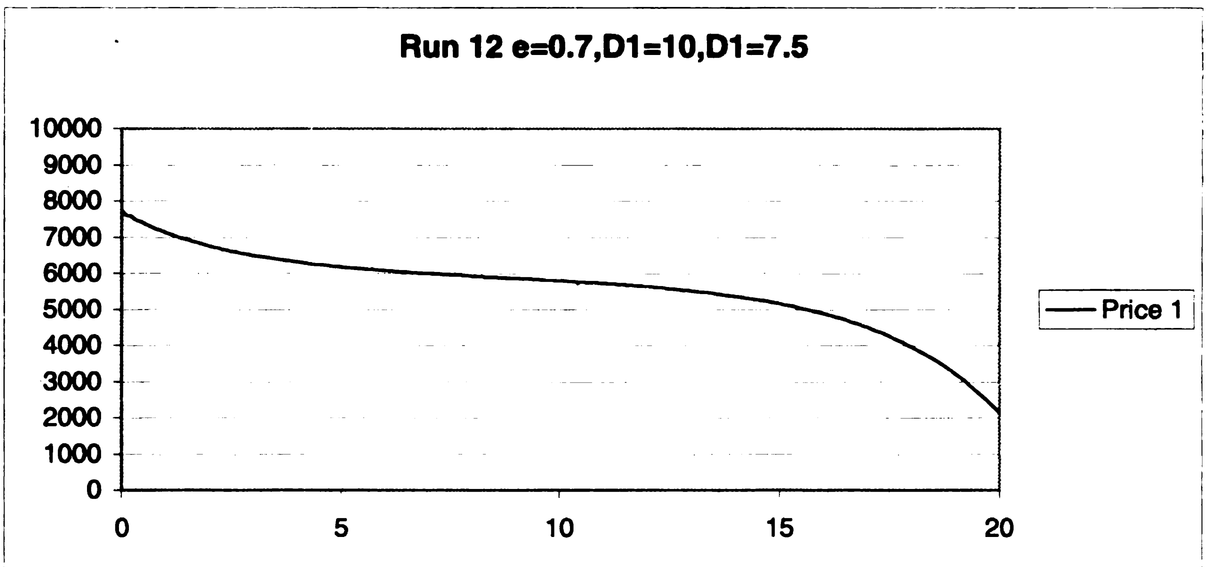


Figure 43 – Run 12 Scenario 1.1

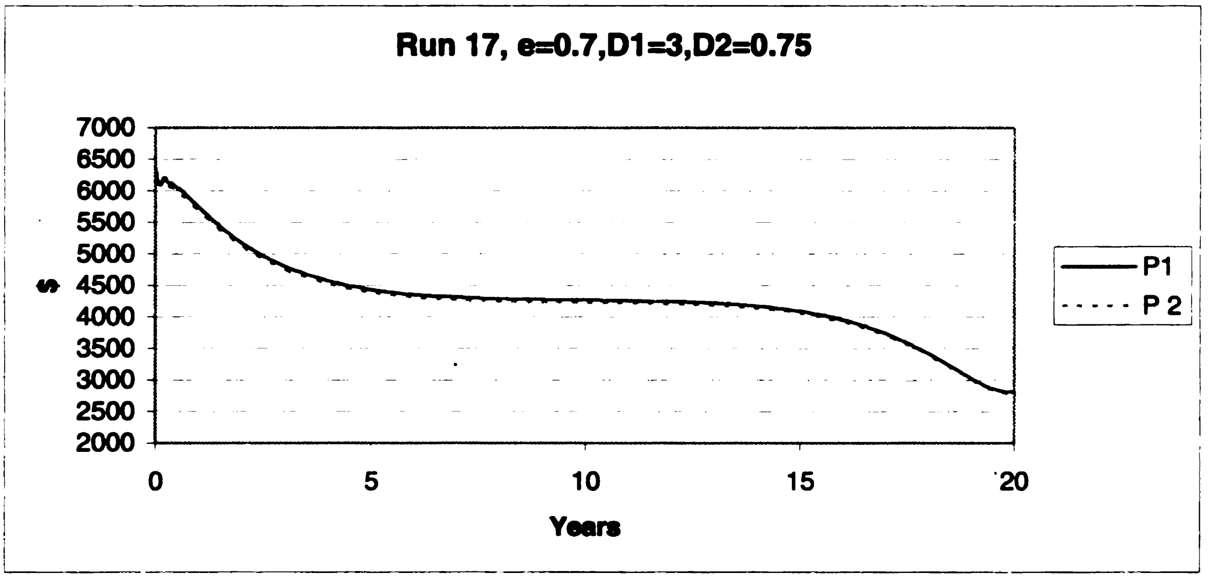


Figure 44 – Run 17 Scenario 1.2

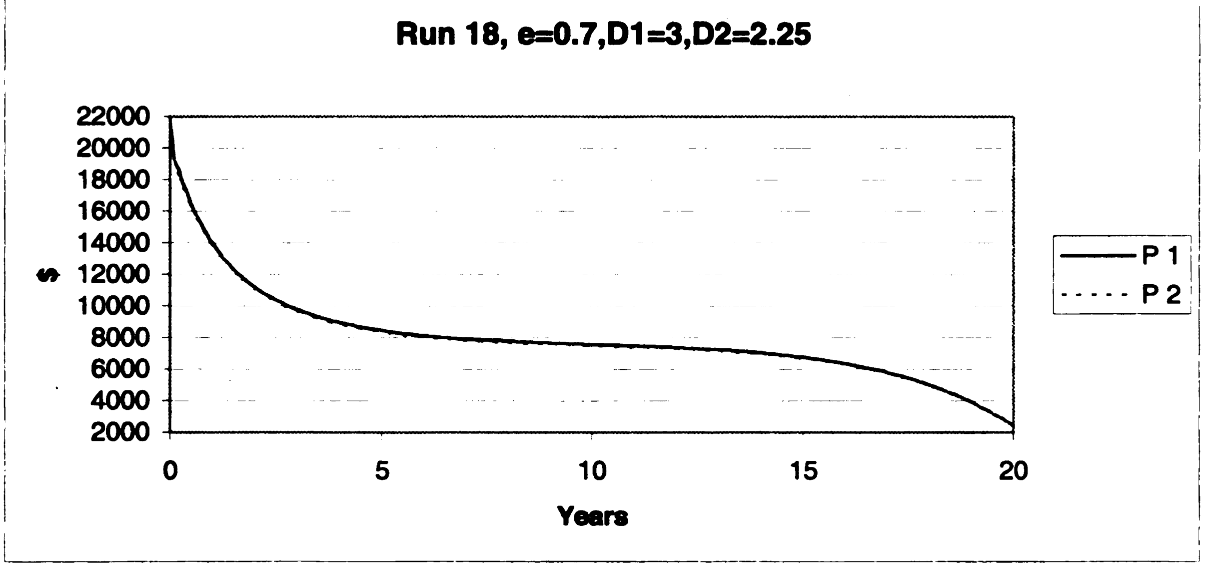


Figure 45– Run 18 Scenario 1.2

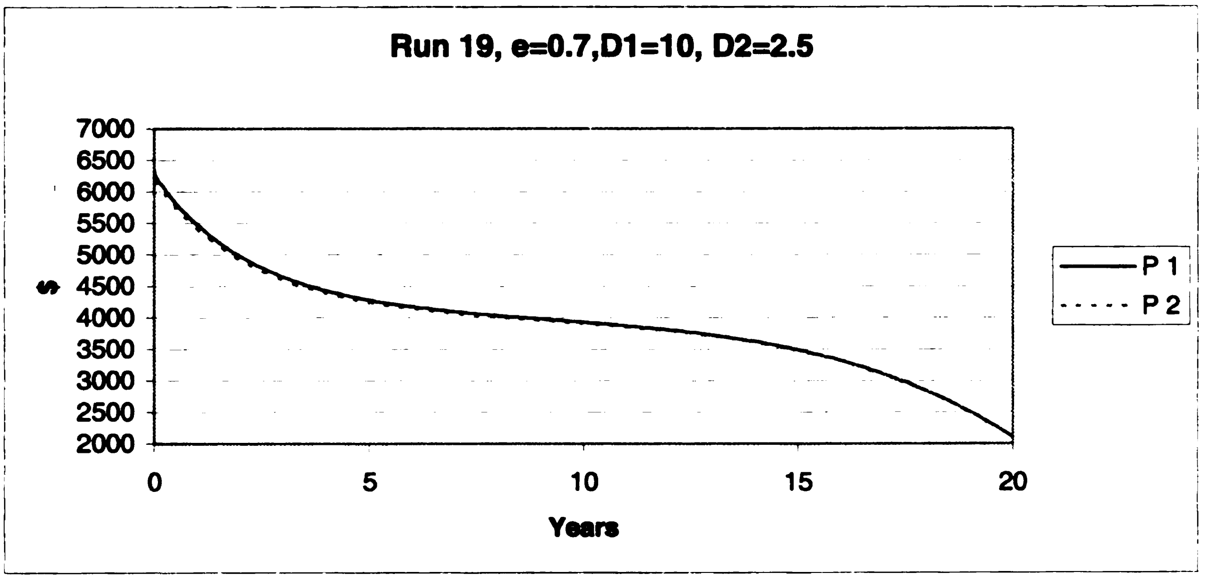


Figure 46 - Run 19 Scenario 1.2

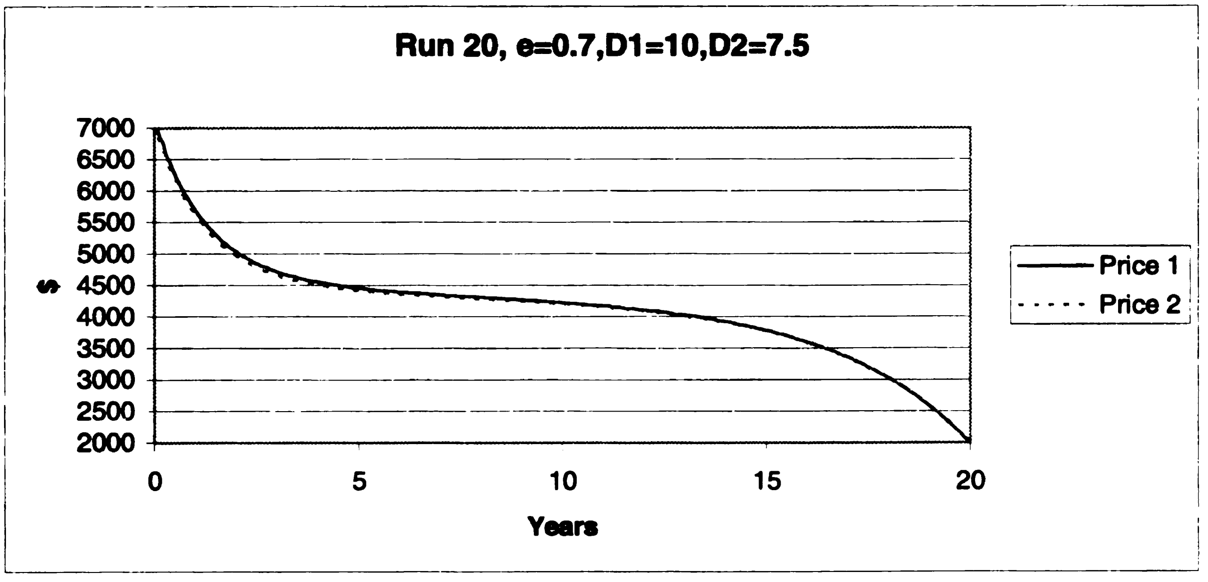


Figure 47 - Run 20 Scenario 1.2

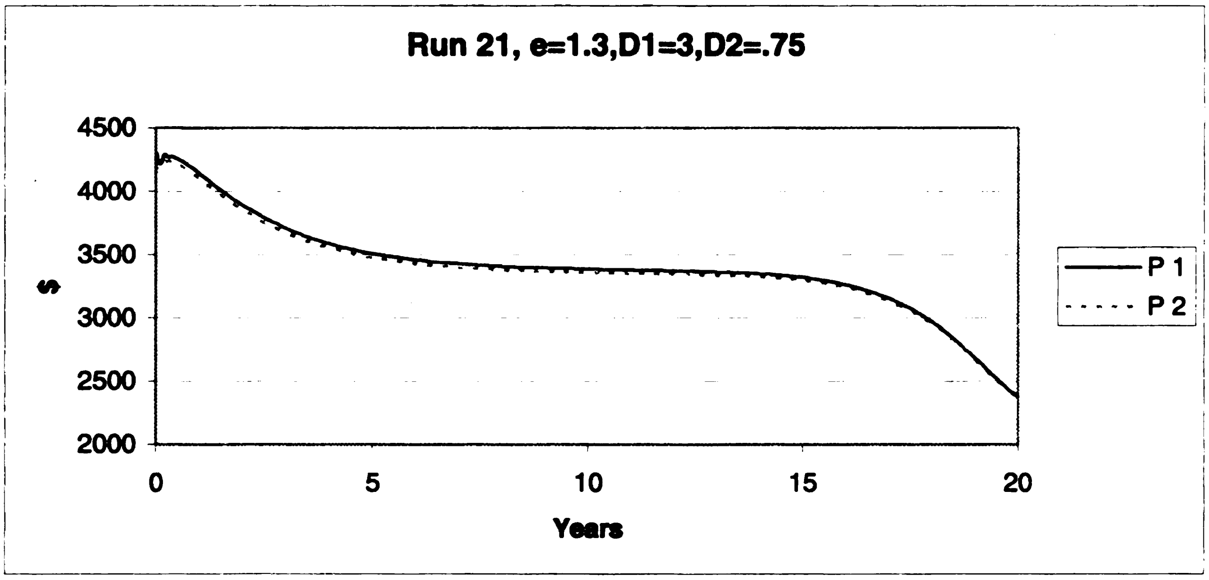


Figure 48 - Run 21 Scenario 1.2

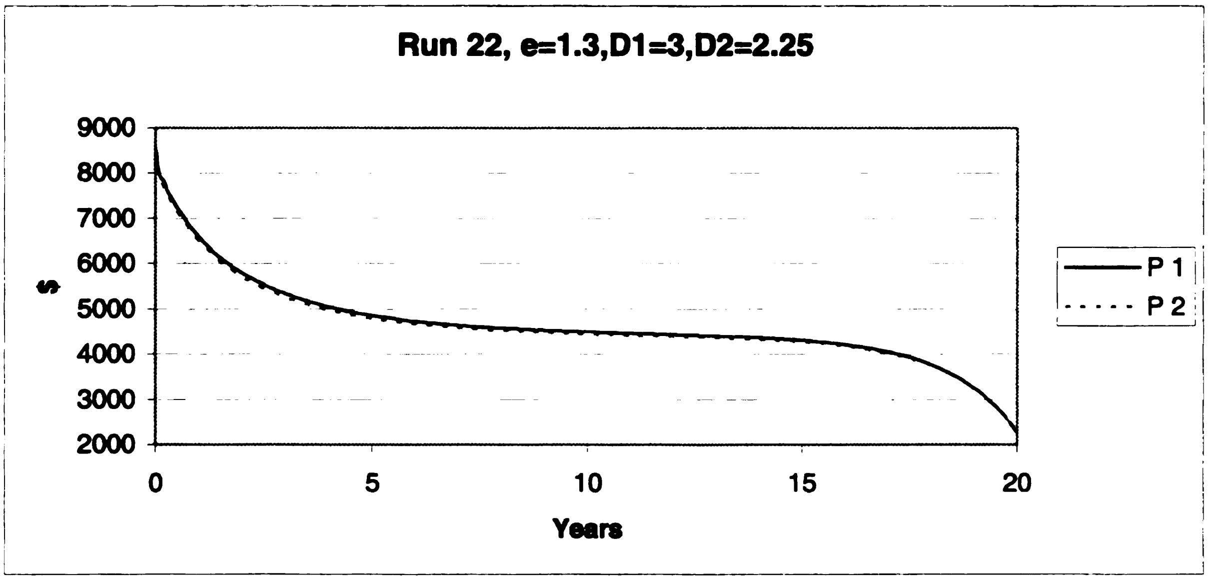


Figure 49 - Run 22 Scenario 1.2

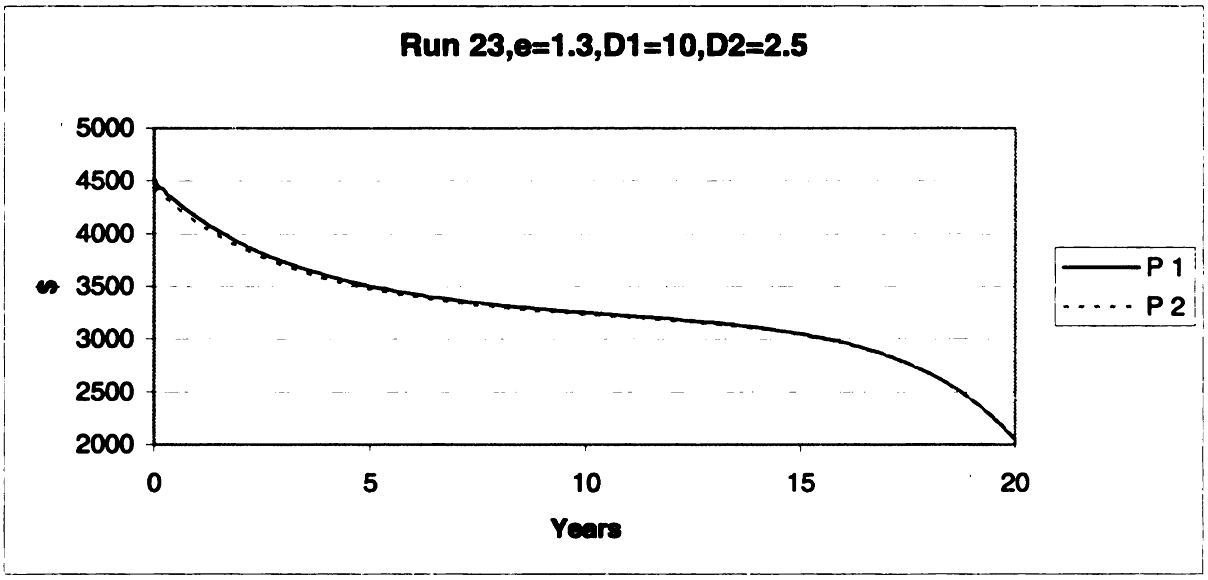


Figure 50 - Run 23 Scenario 1.2

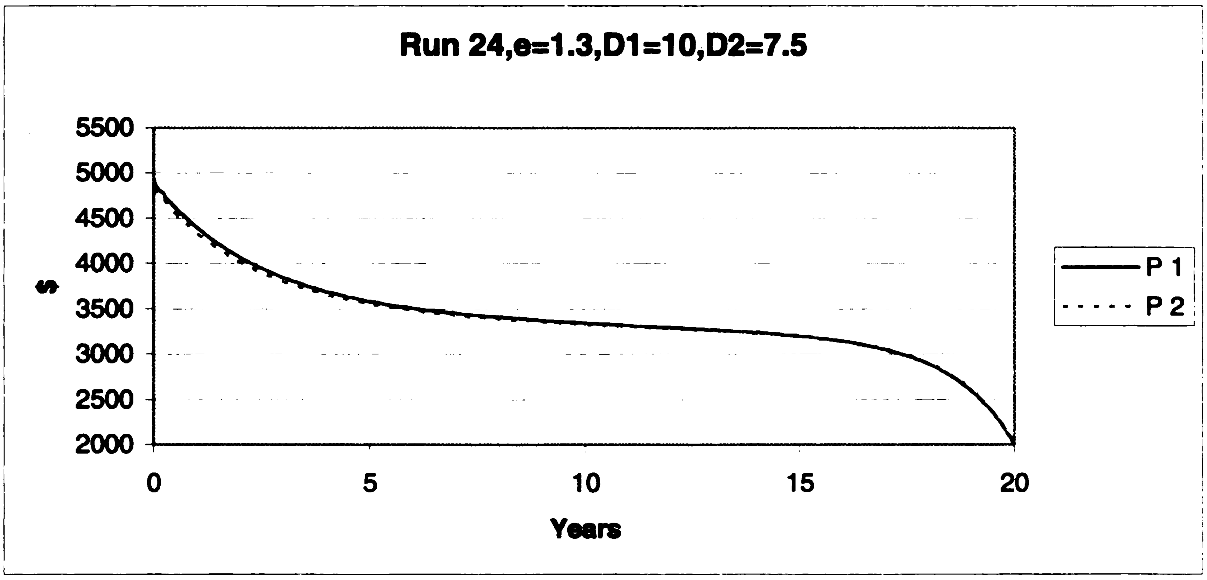


Figure 51 - Run 24 Scenario 1.2

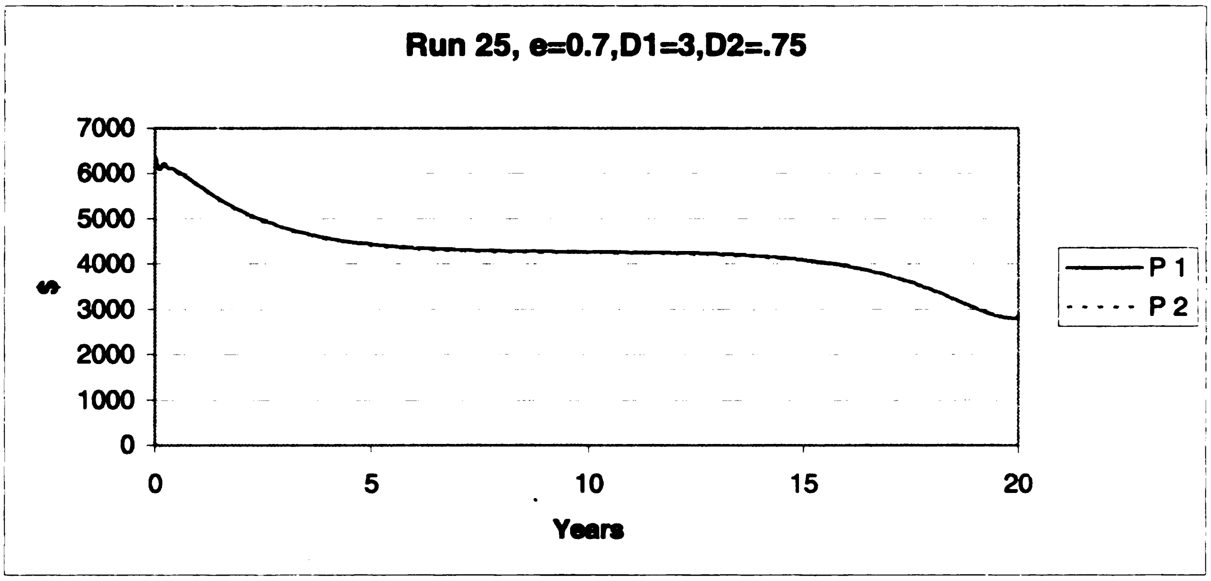


Figure 52 – Run 25 Scenario 1.3

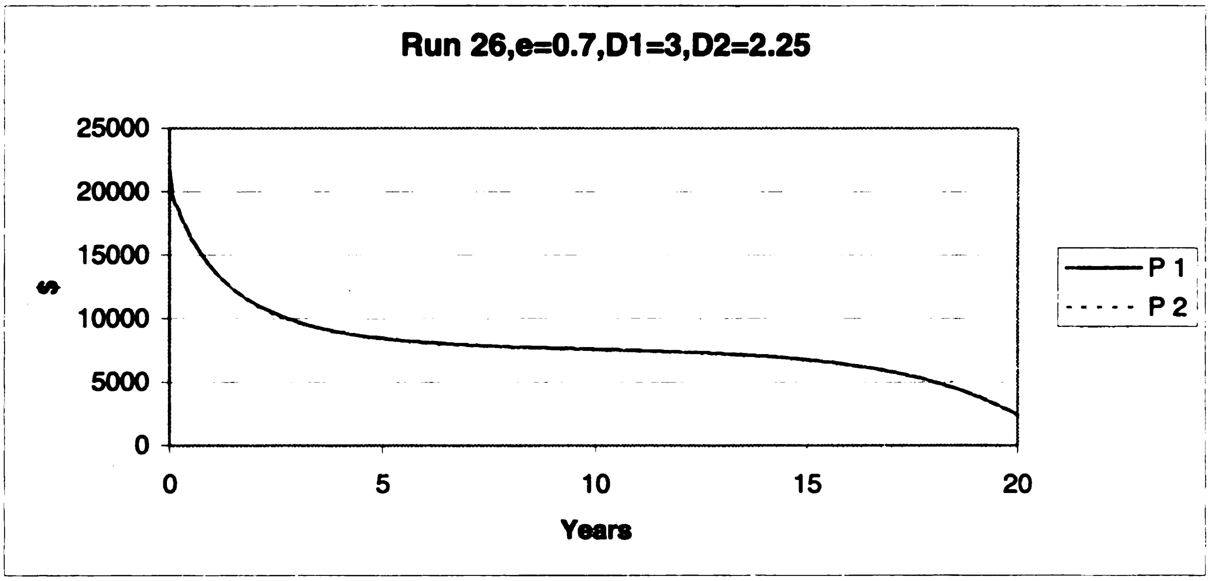


Figure 53 - Run 26 Scenario 1.3

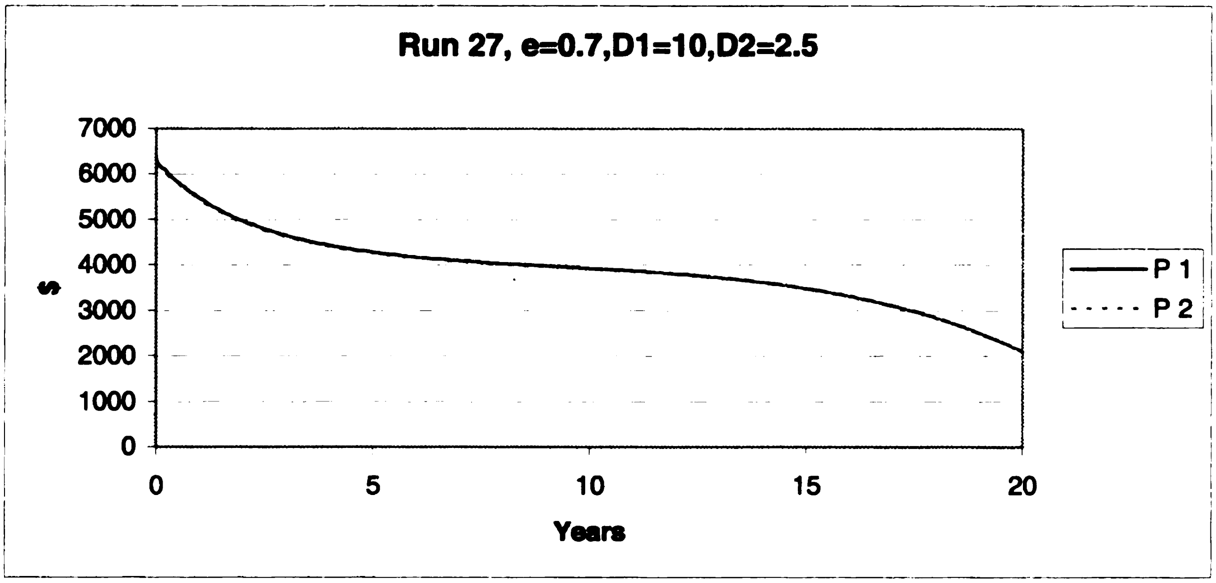


Figure 54- Run 27 Scenario 1.3

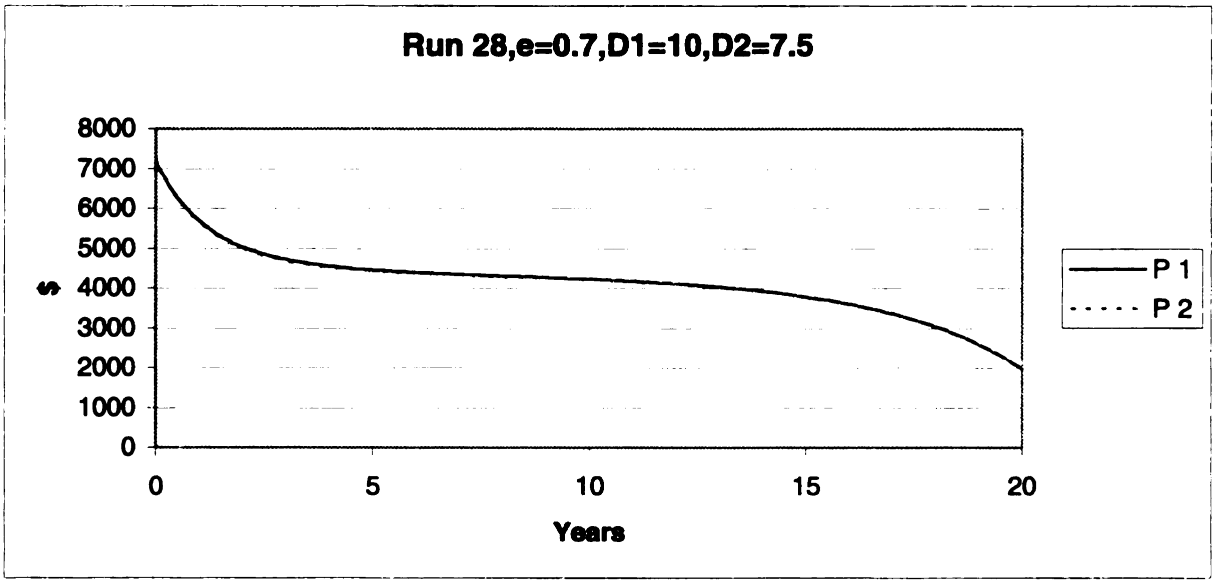


Figure 55- Run 28 Scenario 1.3

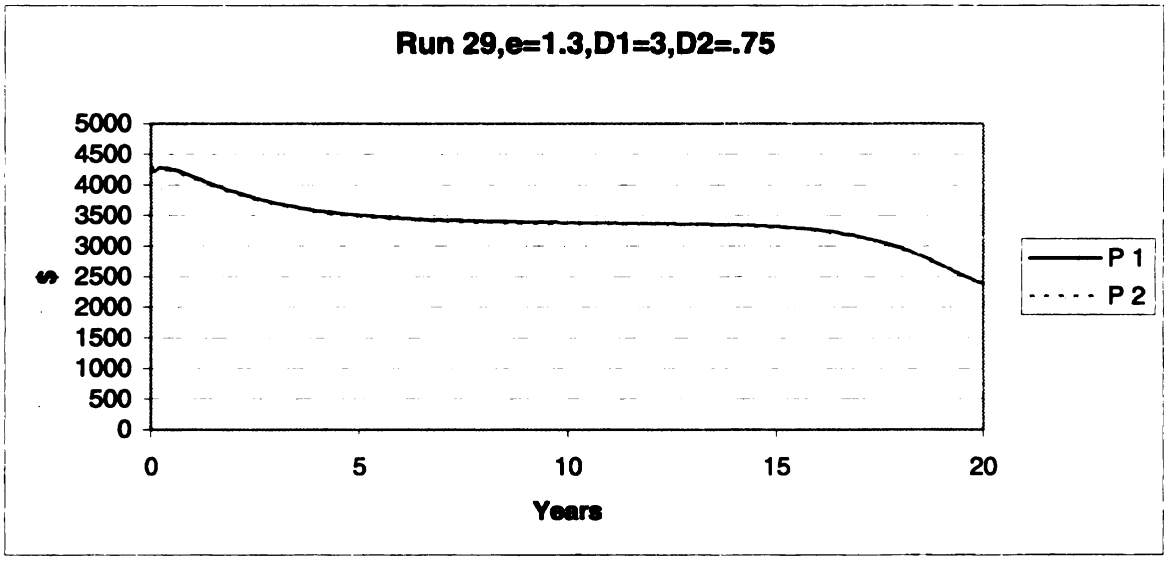


Figure 56- Run 29 Scenario 1.3

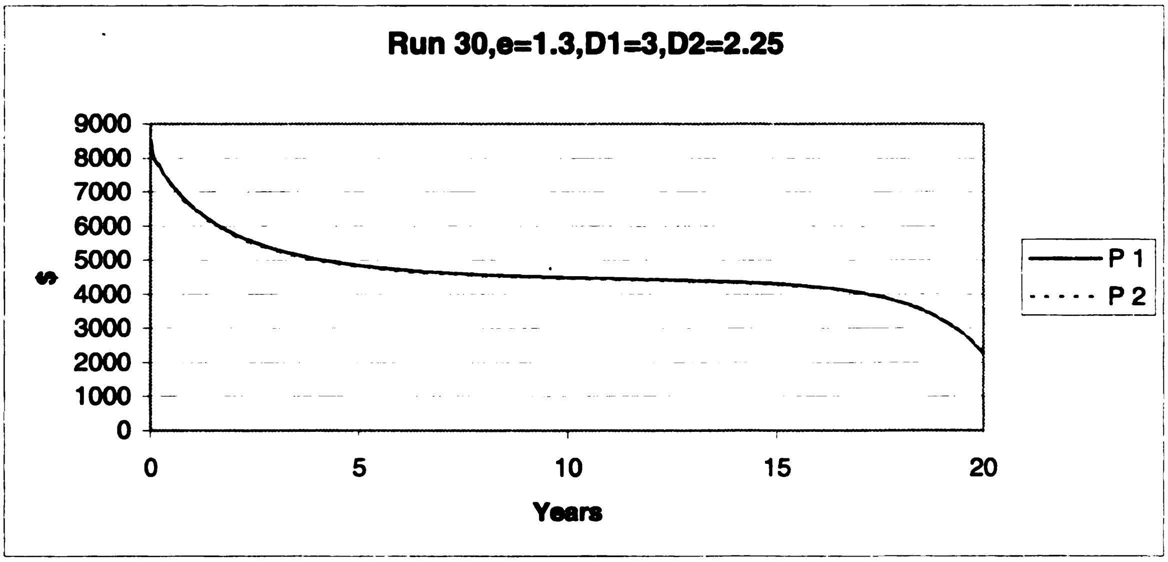


Figure 57- Run 30 Scenario 1.3

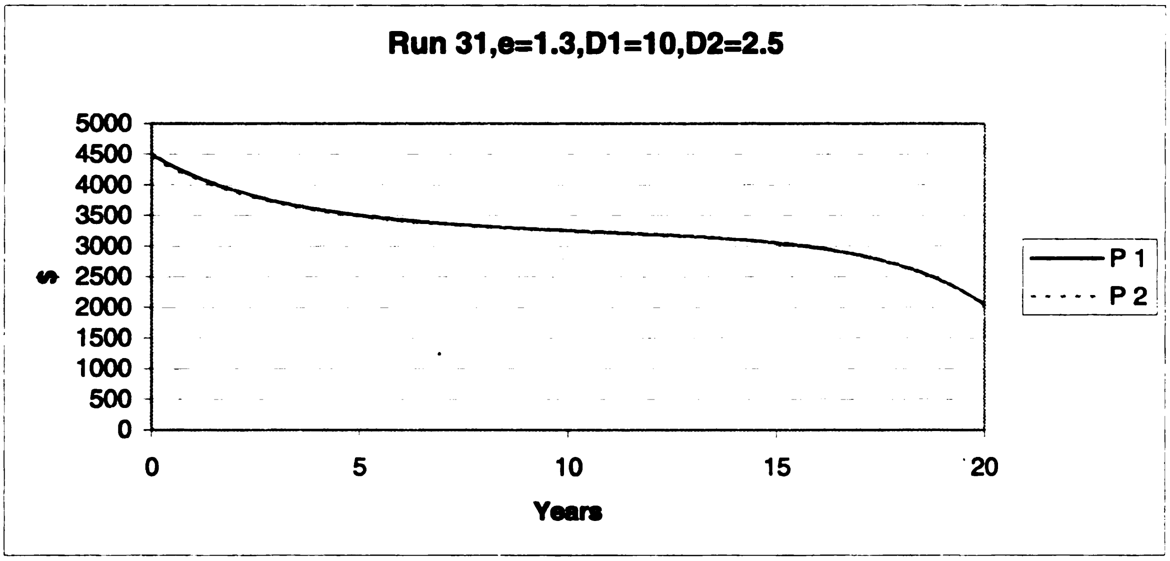


Figure 58- Run 31 Scenario 1.3

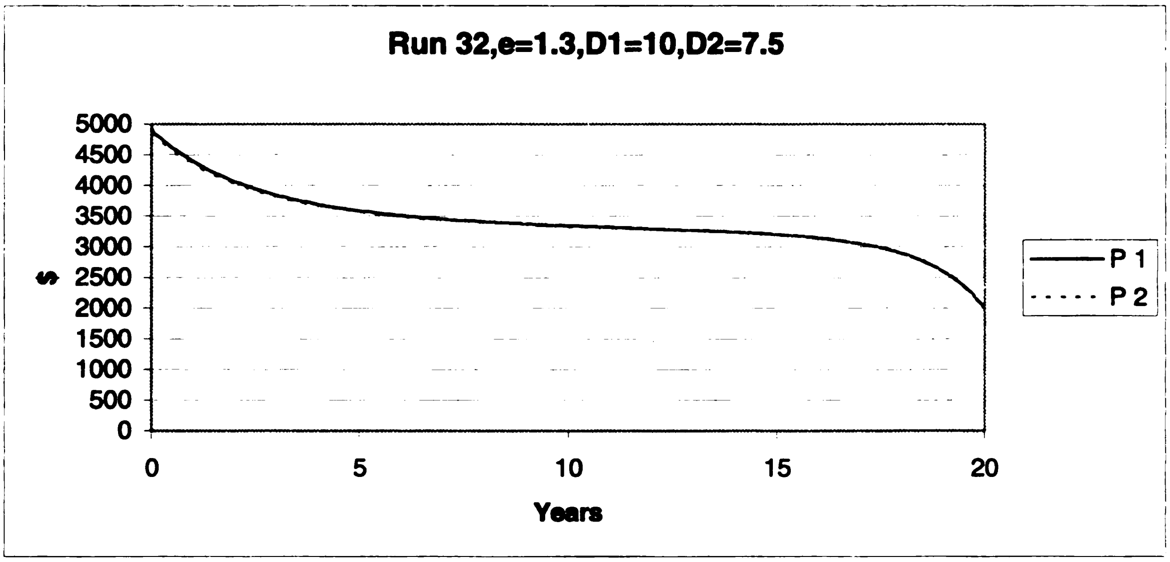


Figure 59- Run 32 Scenario 1.3

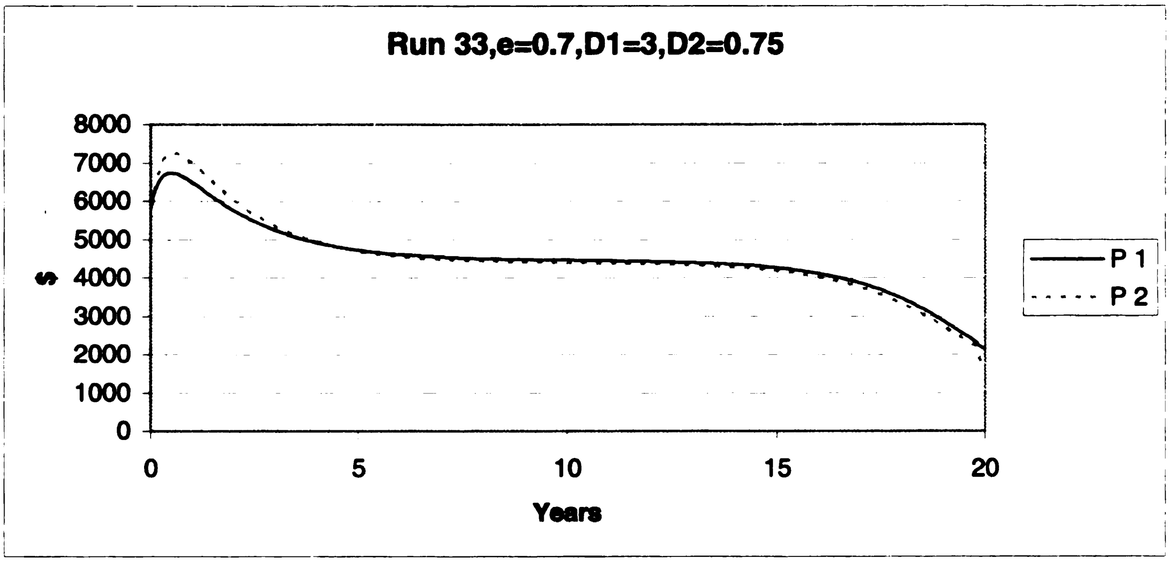


Figure 60 – Run 33 Scenario 1.4

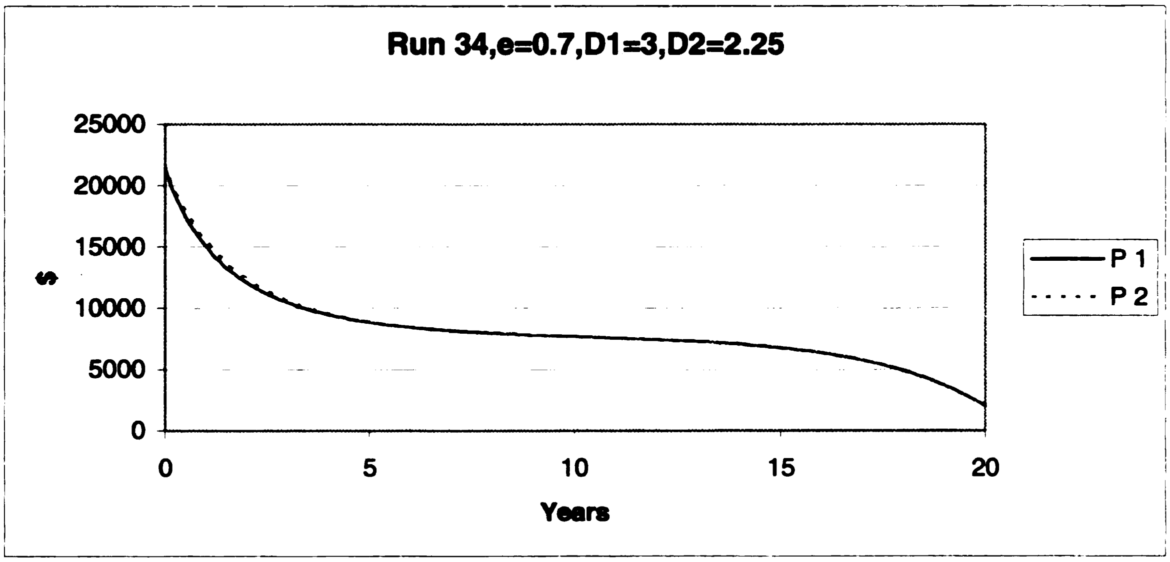


Figure 61– Run 34 Scenario 1.4

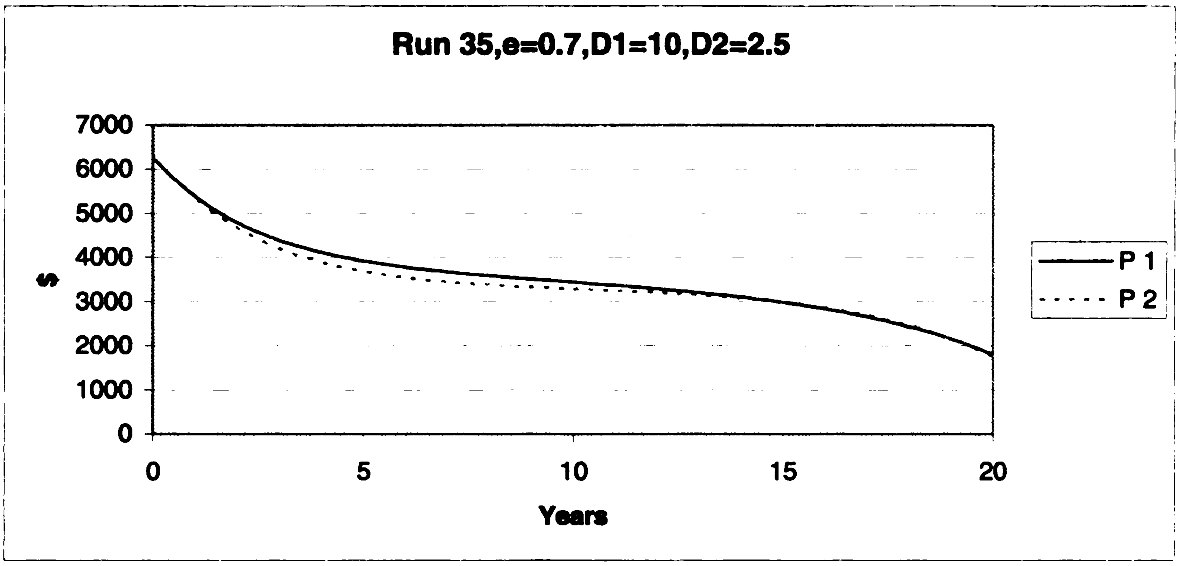


Figure 62– Run 35 Scenario 1.4

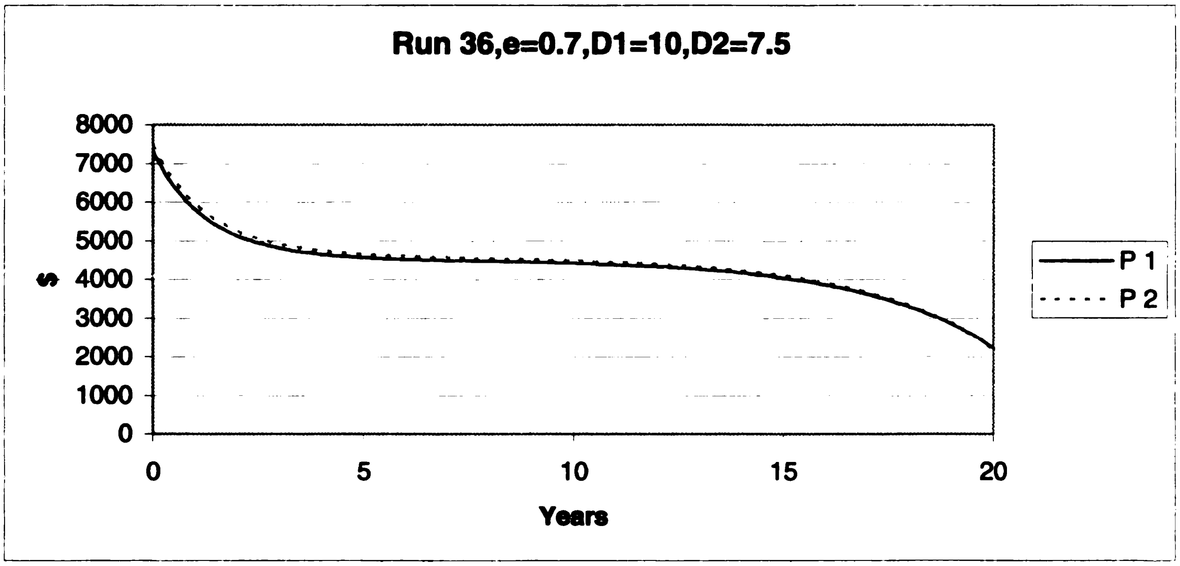


Figure 63– Run 36 Scenario 1.4

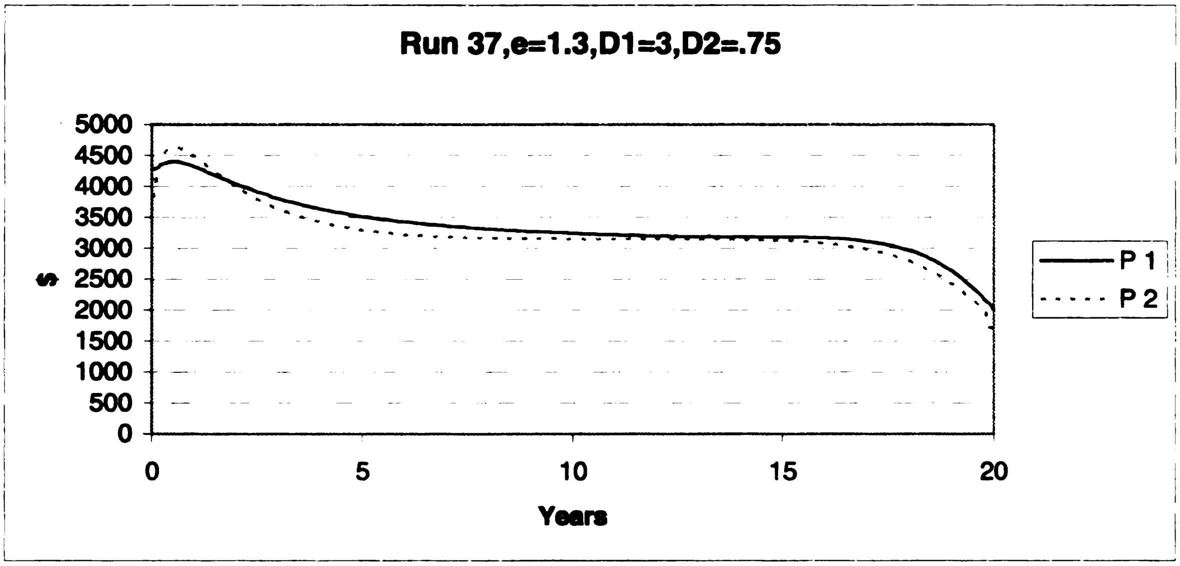


Figure 64– Run 37 Scenario 1.4

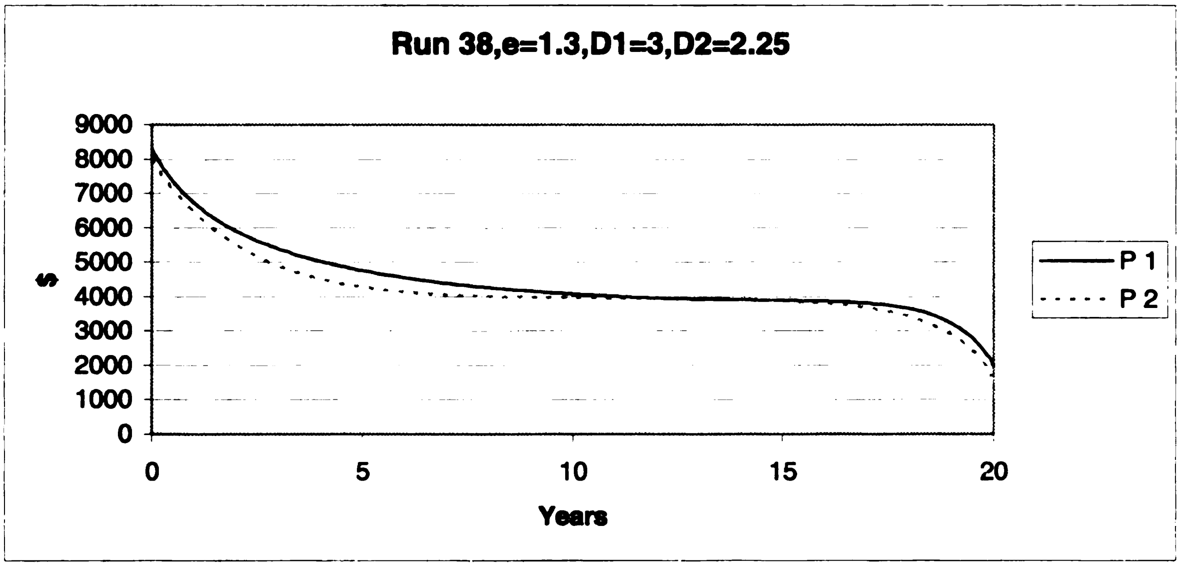


Figure 65– Run 38 Scenario 1.4

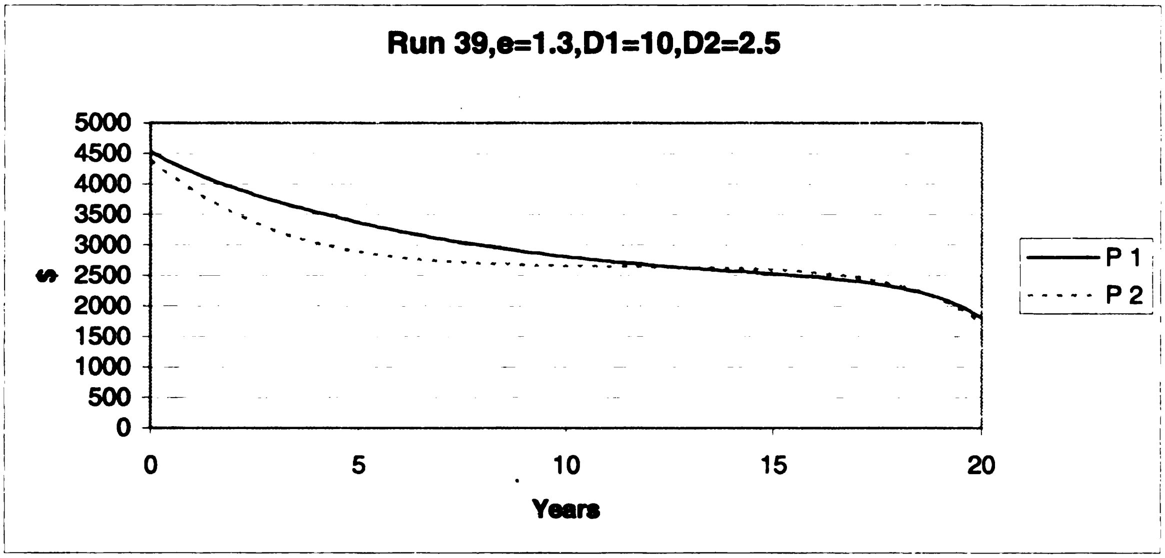


Figure 66– Run 40 Scenario 1.4

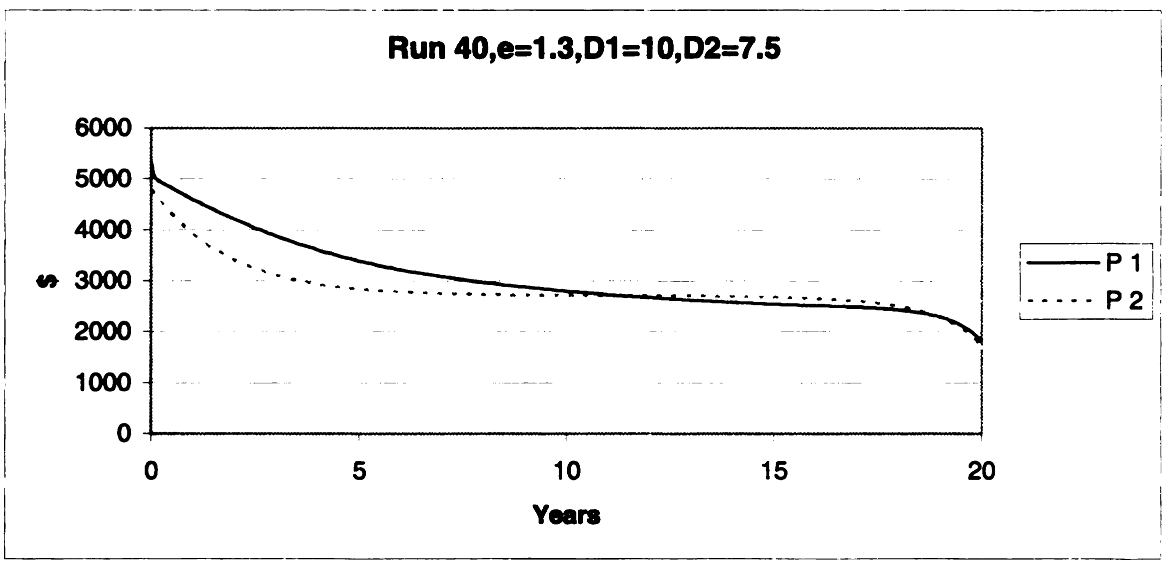


Figure 67– Run 40 Scenario 1.4

Appendix 2

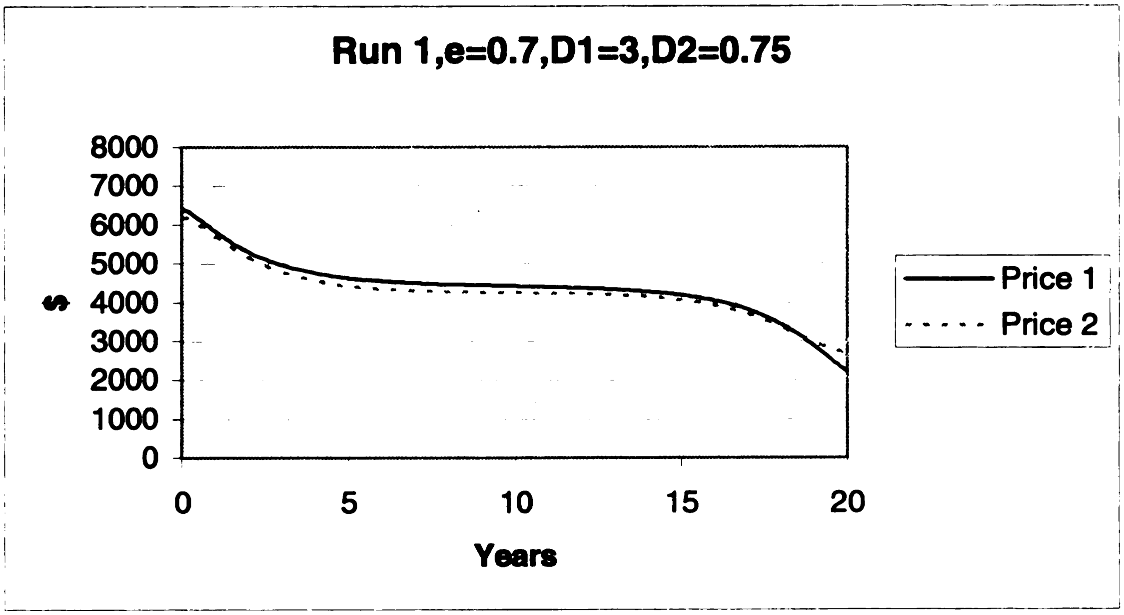


Figure 68 – Run 1 Scenario 2.0

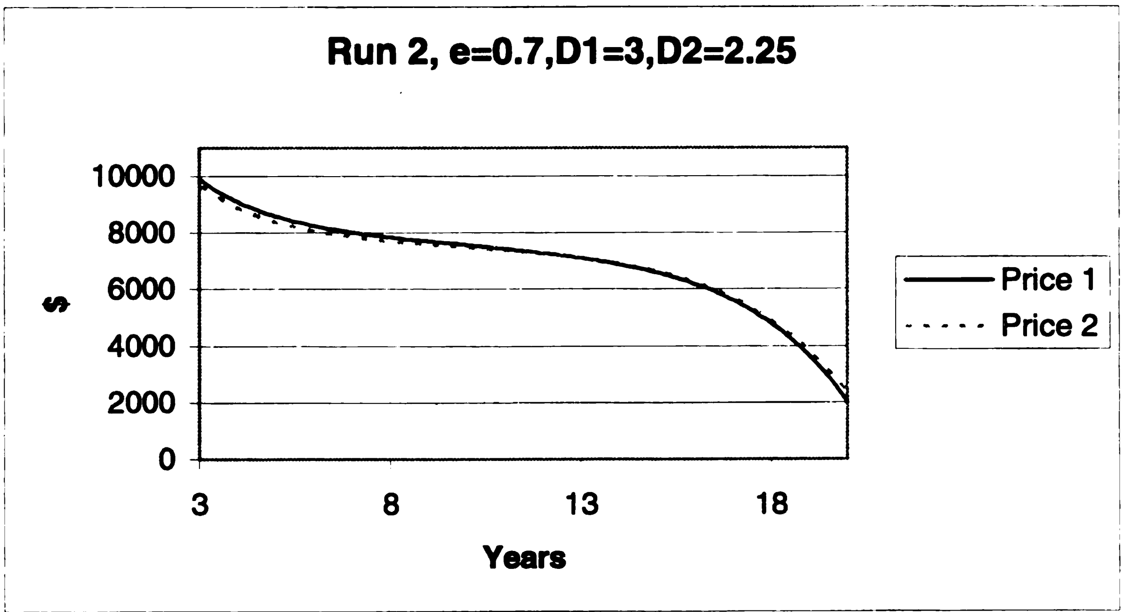


Figure 69– Run 2 Scenario 2.0

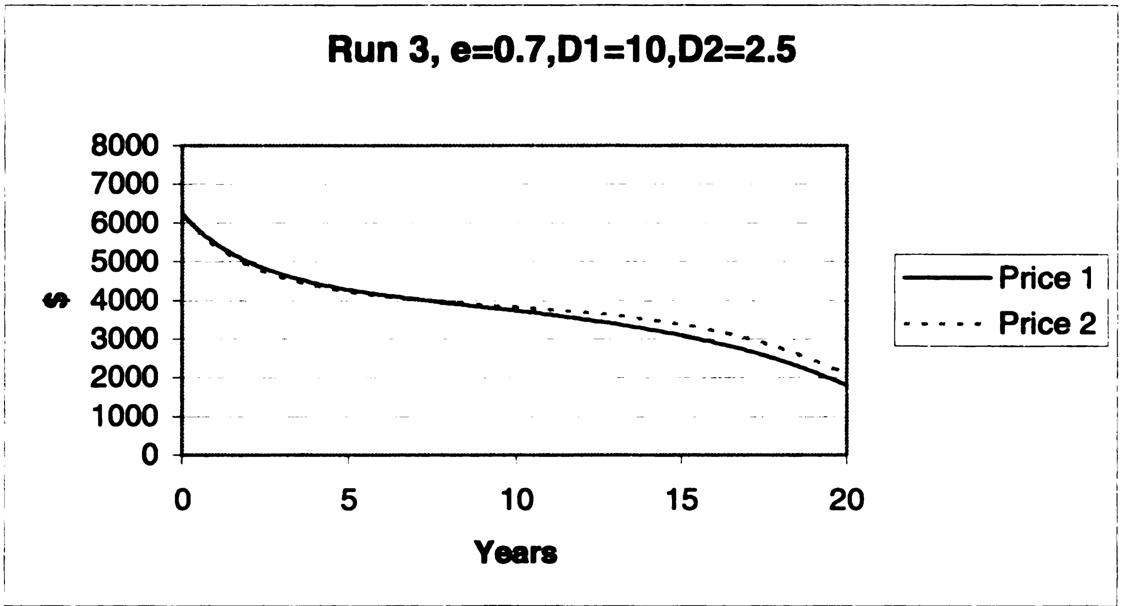


Figure 70– Run 3 Scenario 2.0

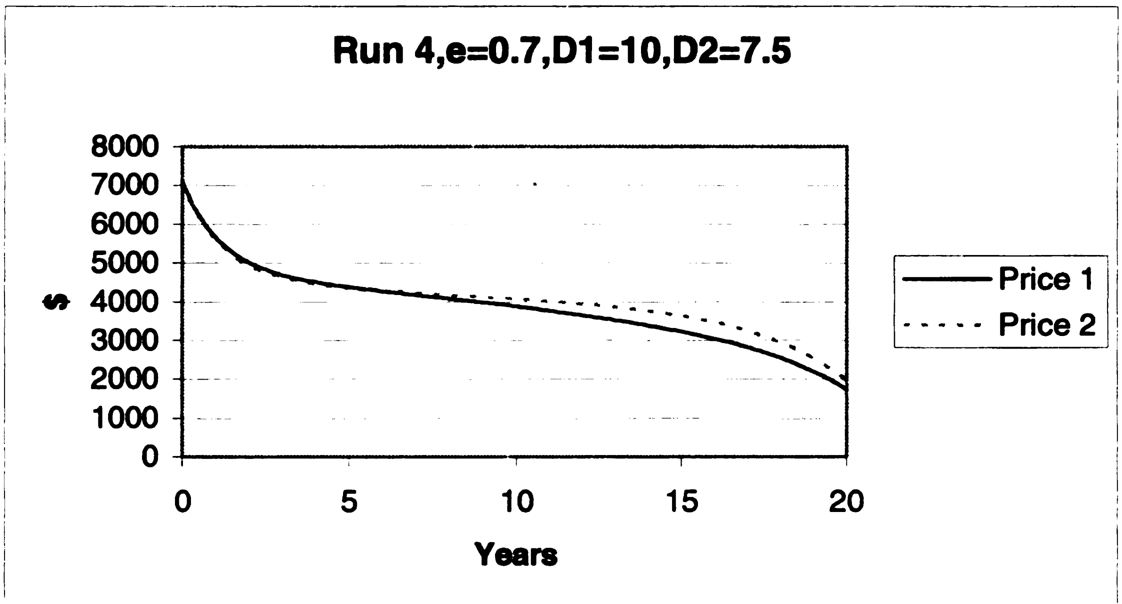


Figure 71– Run 4 Scenario 2.0

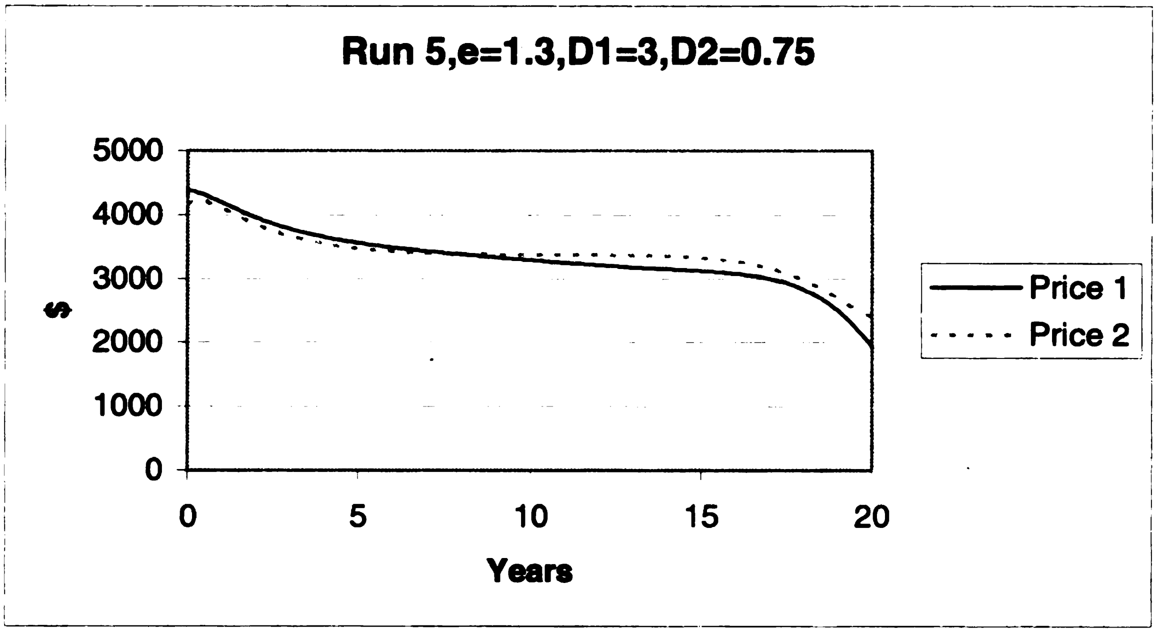


Figure 72– Run 5 Scenario 2.0

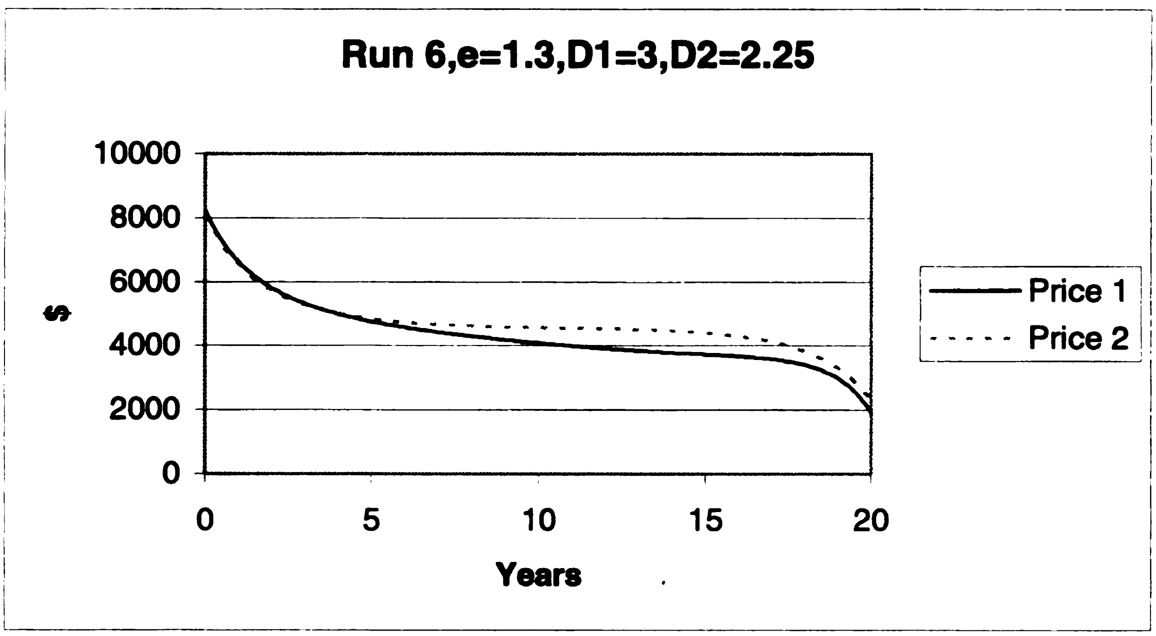


Figure 73– Run 6 Scenario 2.0

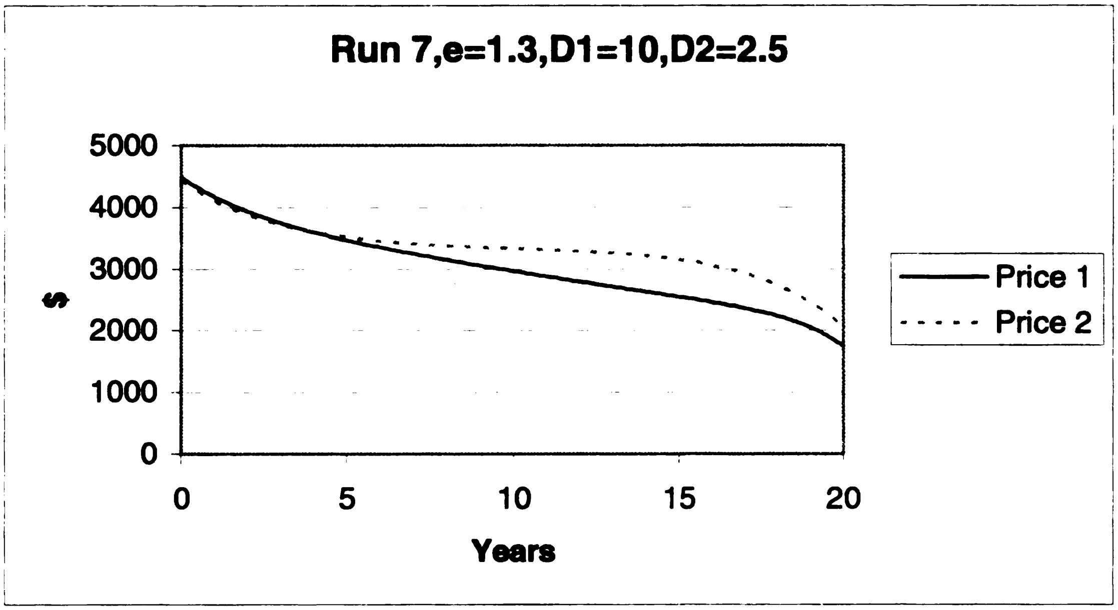


Figure 74– Run 7 Scenario 2.0

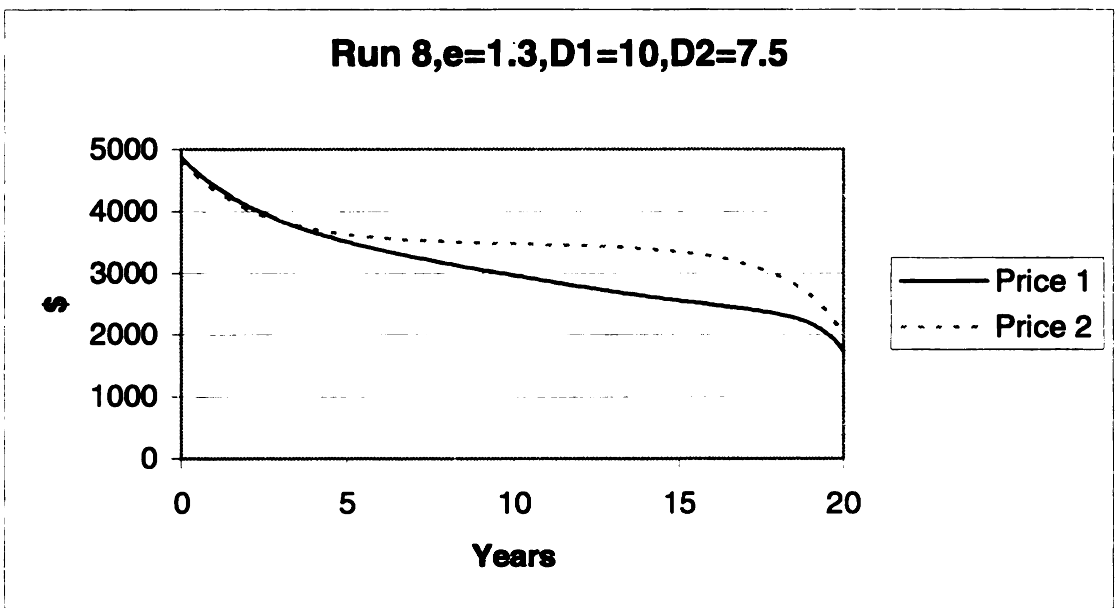


Figure 75– Run 8 Scenario 2.0

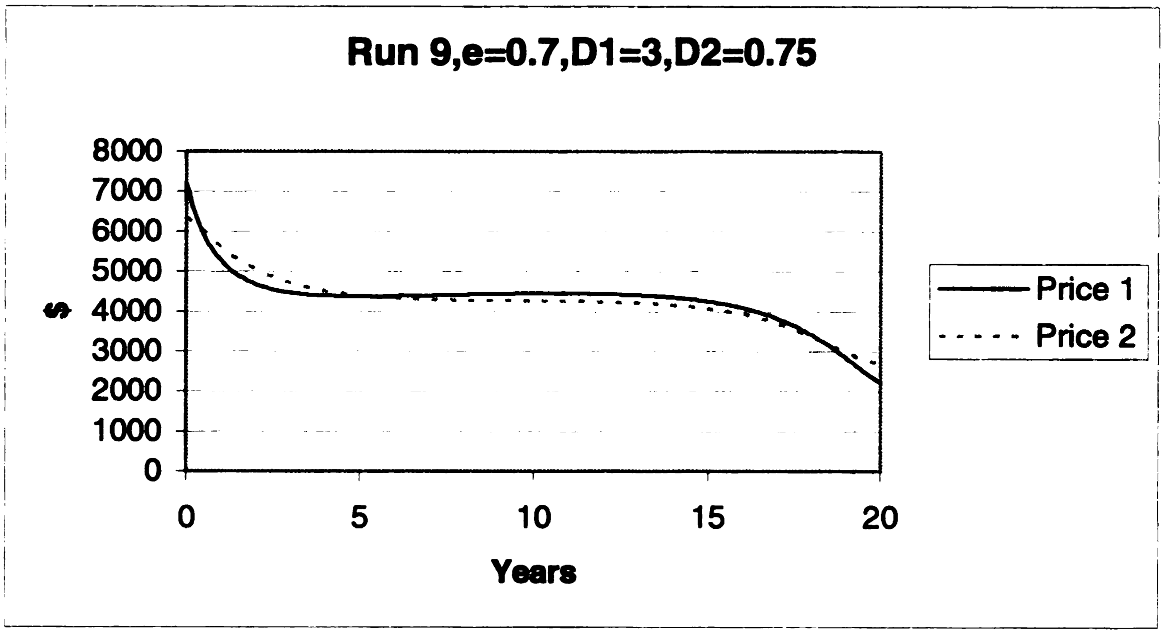


Figure 76 – Run 9 Scenario 2.1

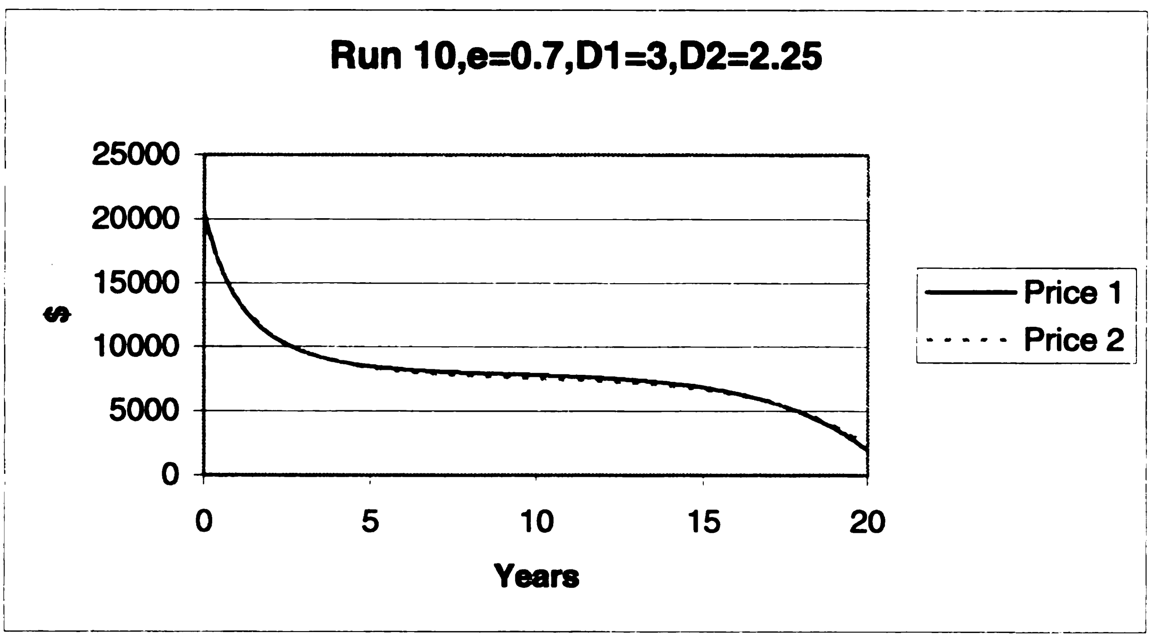


Figure 77– Run 10 Scenario 2.1

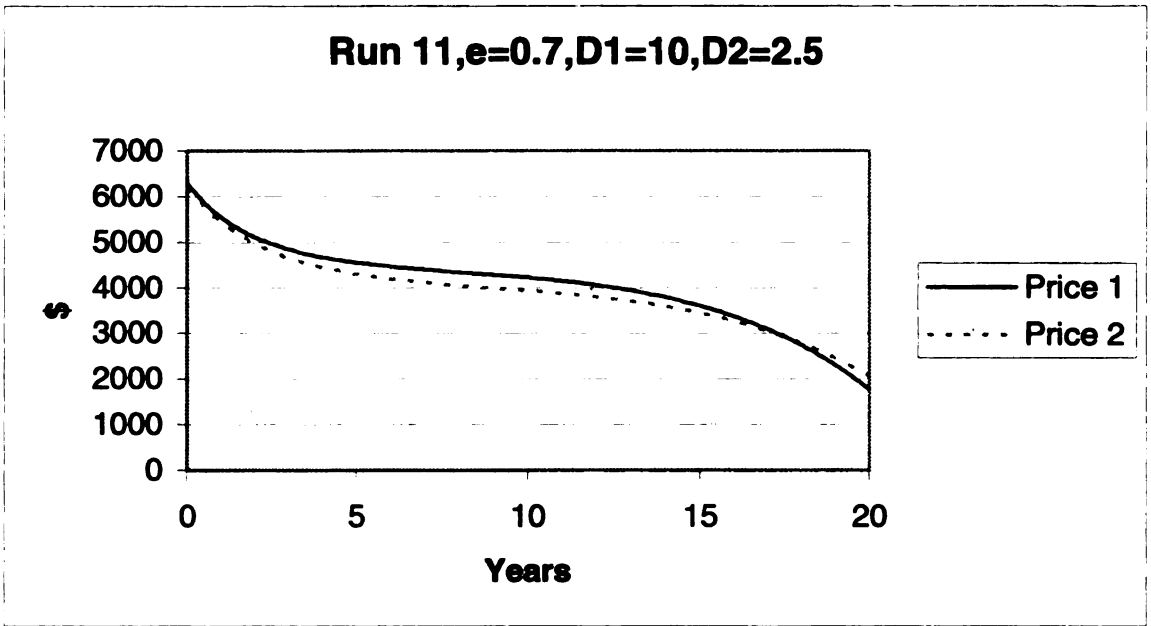


Figure 78 – Run 11 Scenario 2.1

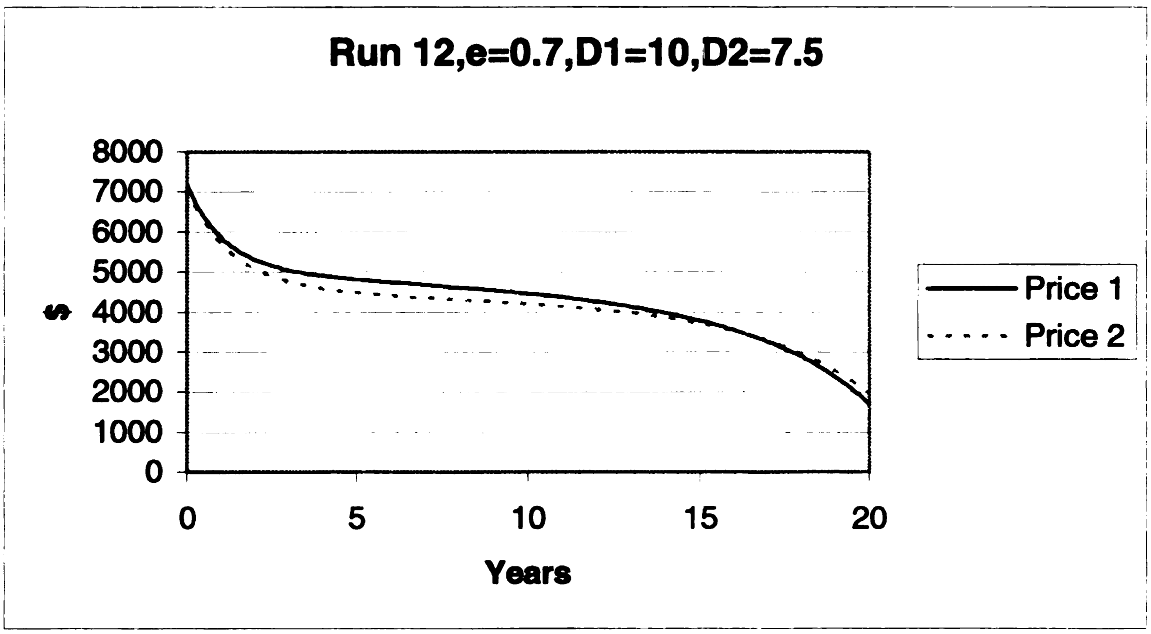


Figure 79 – Run 12 Scenario 2.1

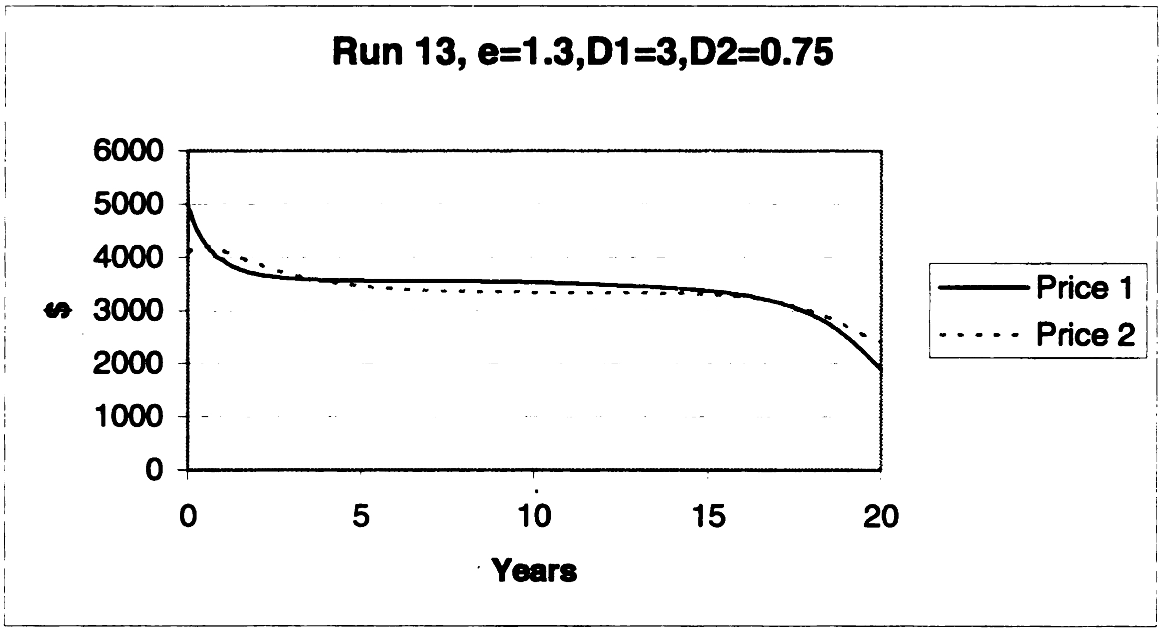


Figure 80– Run 13 Scenario 2.1

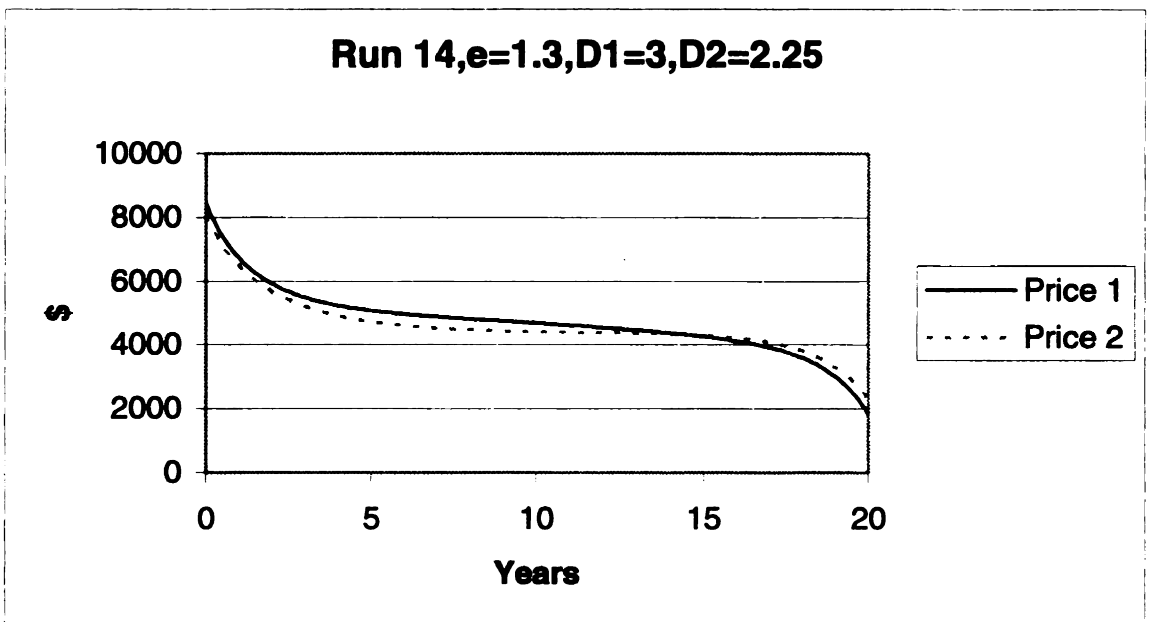


Figure 81– Run14 Scenario 2.1

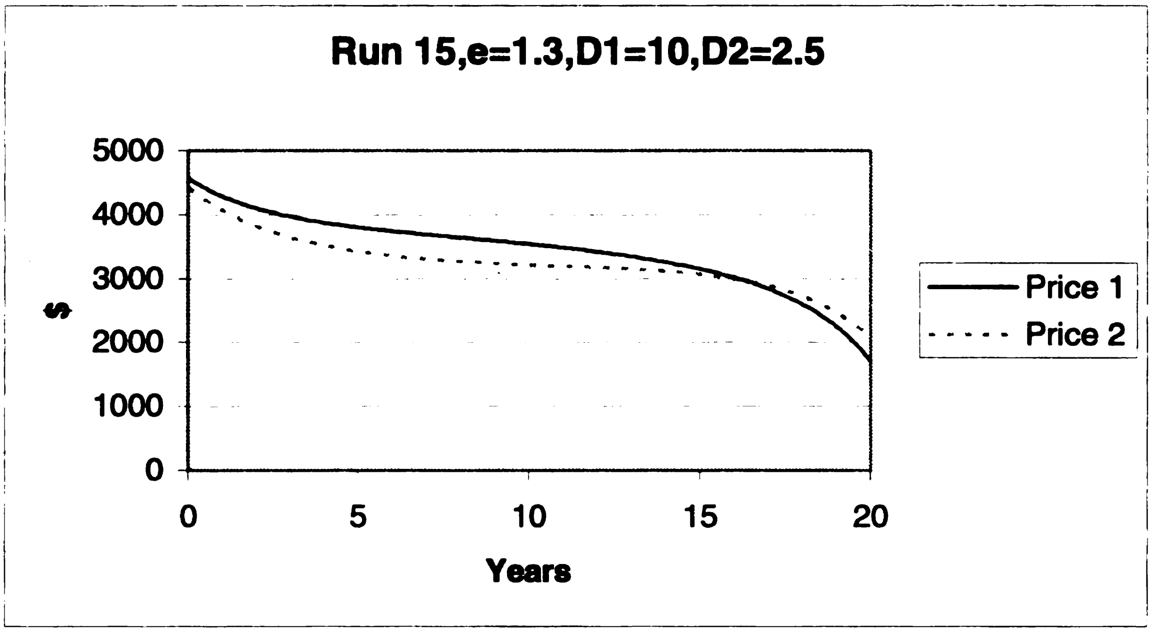


Figure 82– Run 15 Scenario 2.1

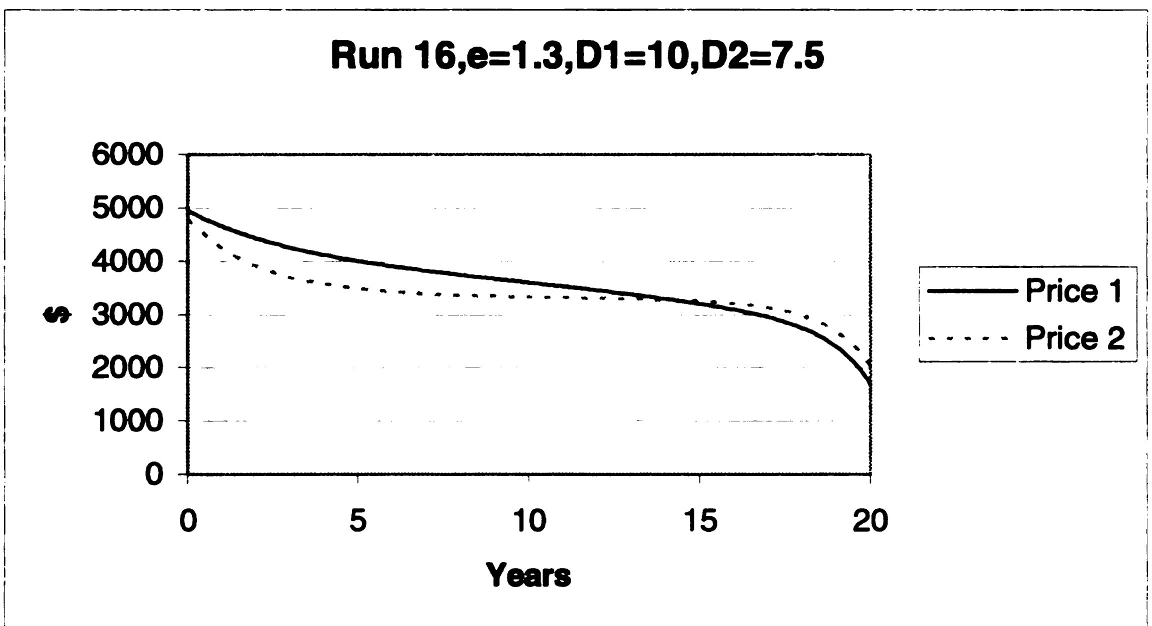


Figure 83– Run 16 Scenario 2.1

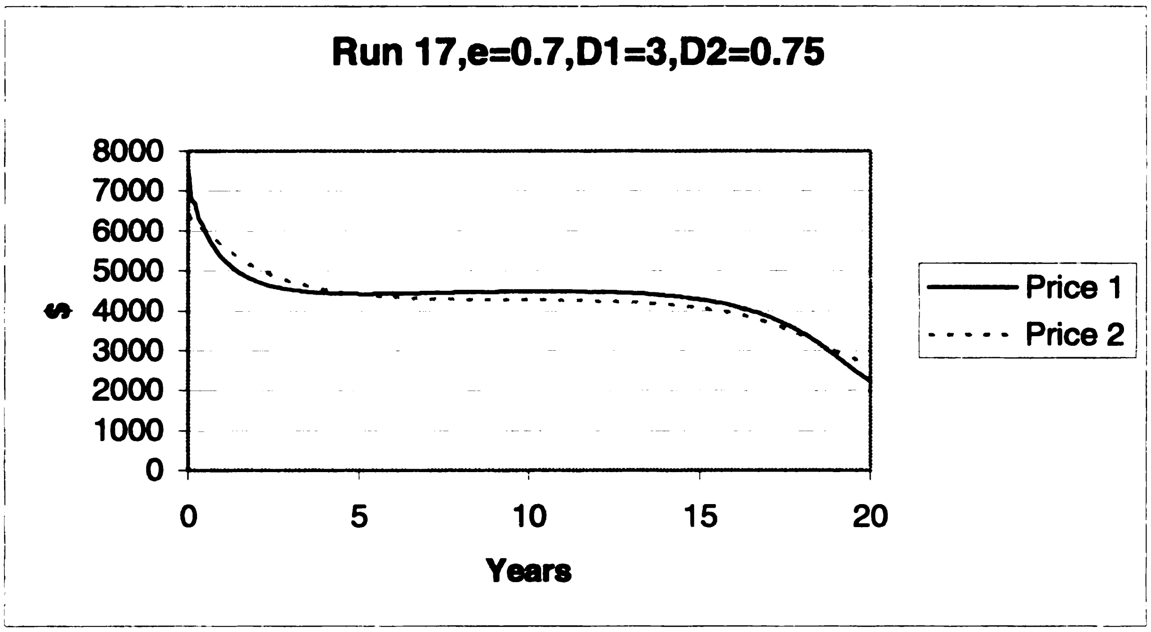


Figure 84 – Run 17 Scenario 2.2

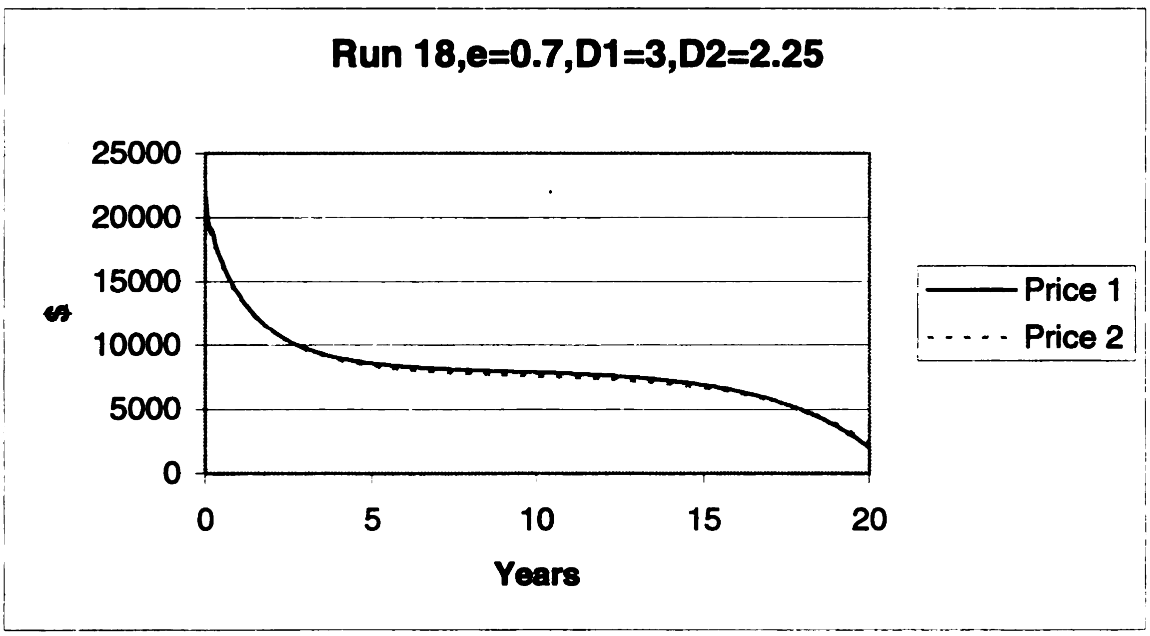


Figure 85– Run 18 Scenario 2.2

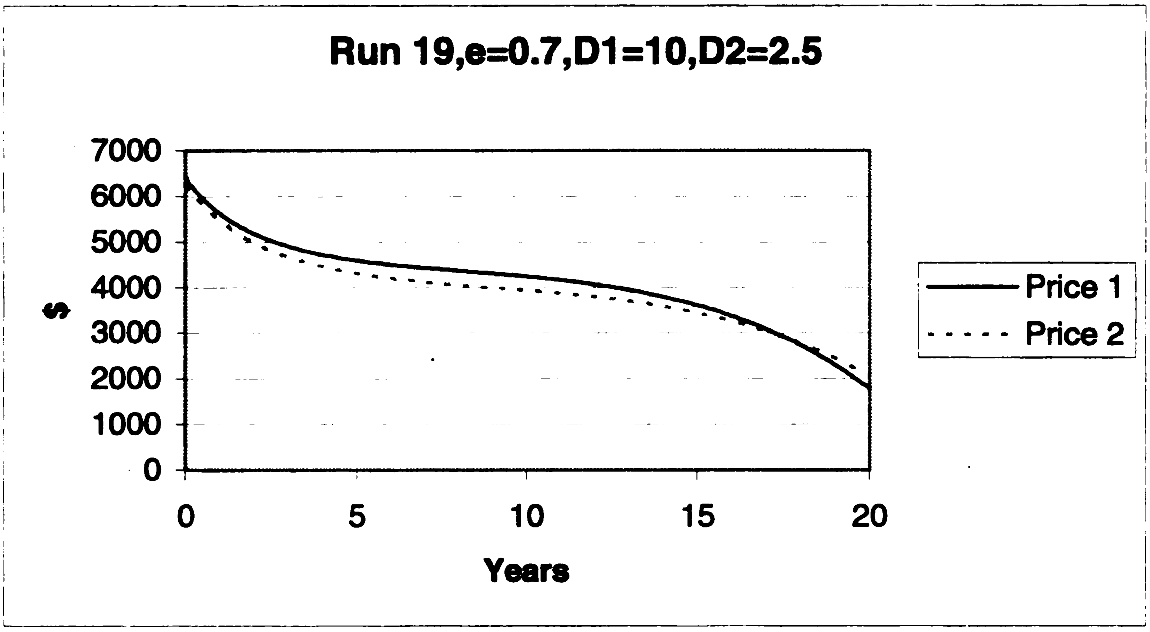


Figure 86– Run 19 Scenario 2.2

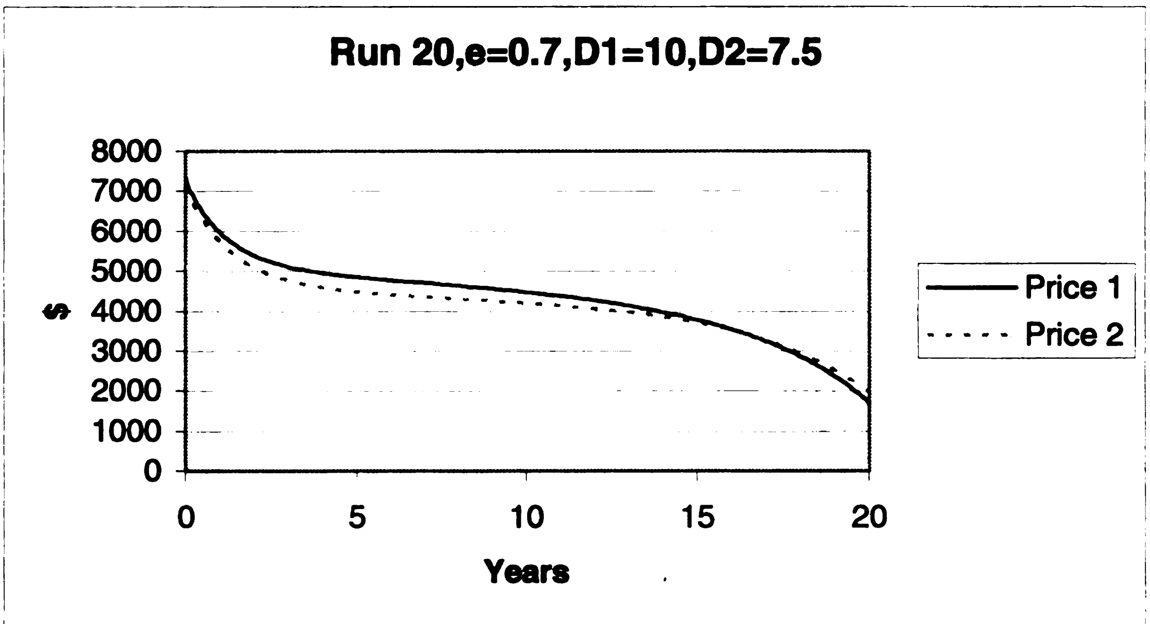


Figure 87– Run 20 Scenario 2.2

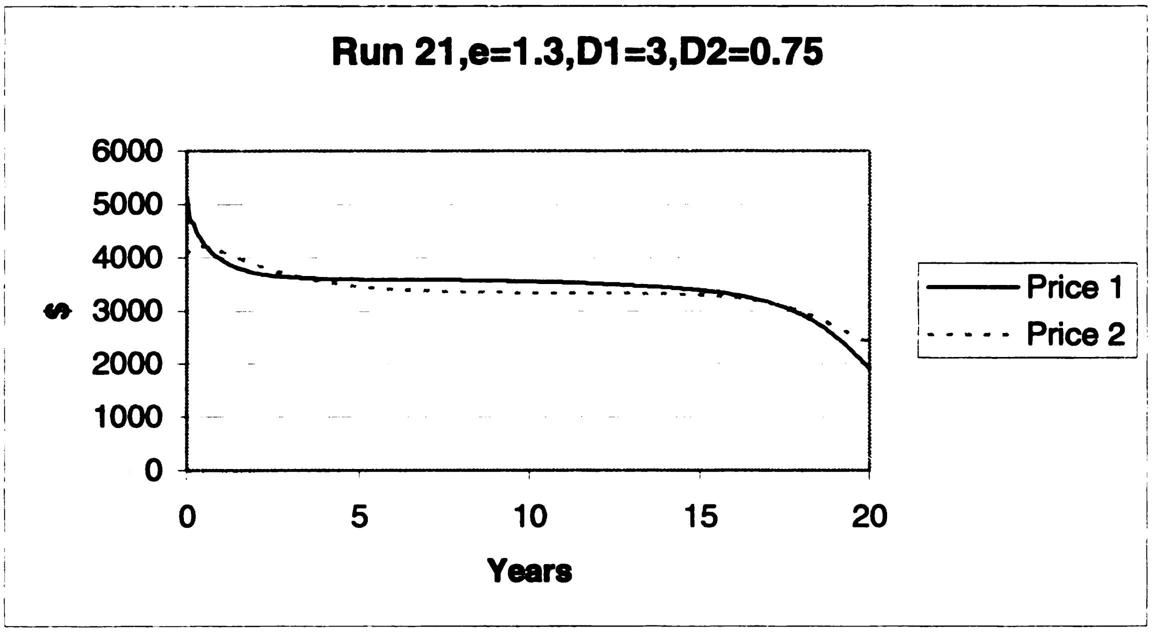


Figure 88– Run 21 Scenario 2.2

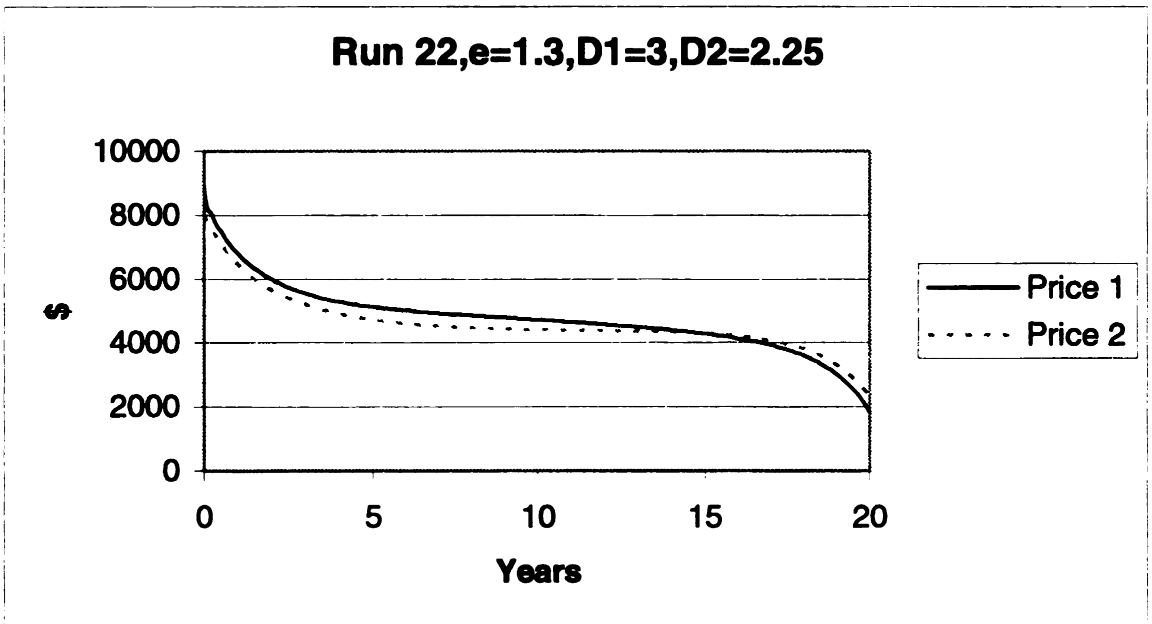


Figure 89– Run 22 Scenario 2.2

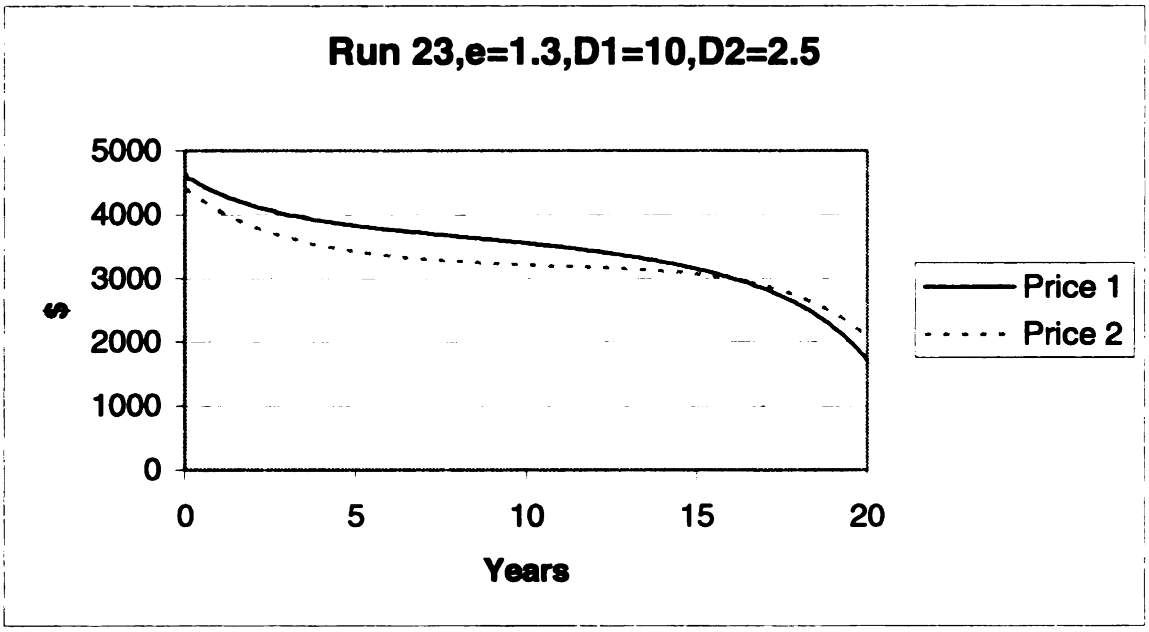


Figure 90– Run 23 Scenario 2.2

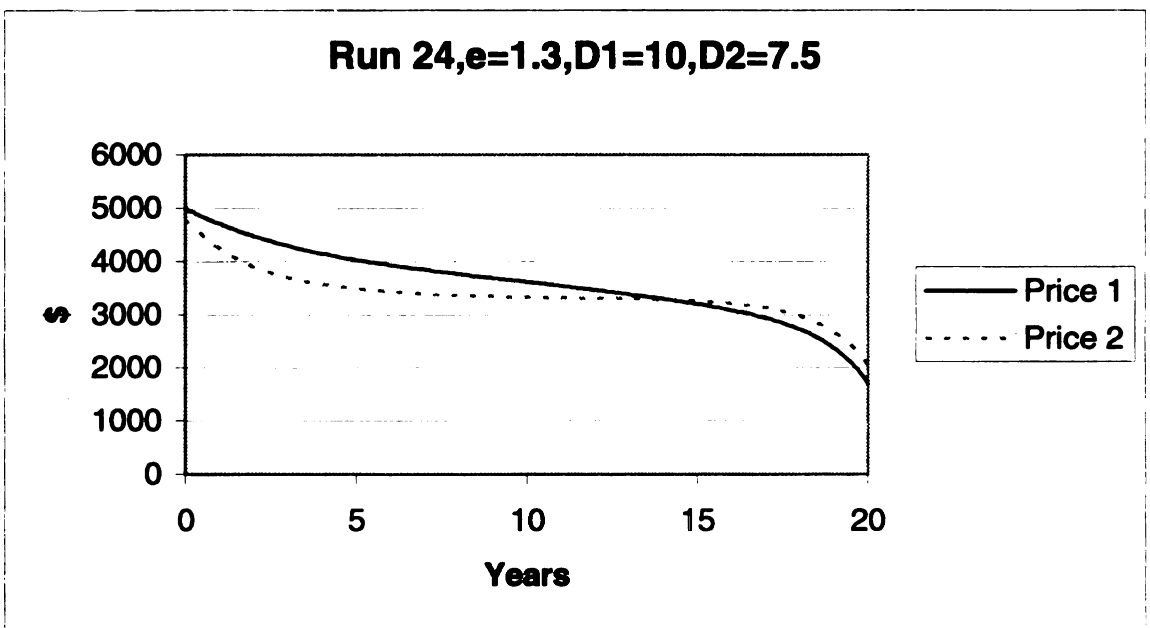


Figure 91– Run 24 Scenario 2.2

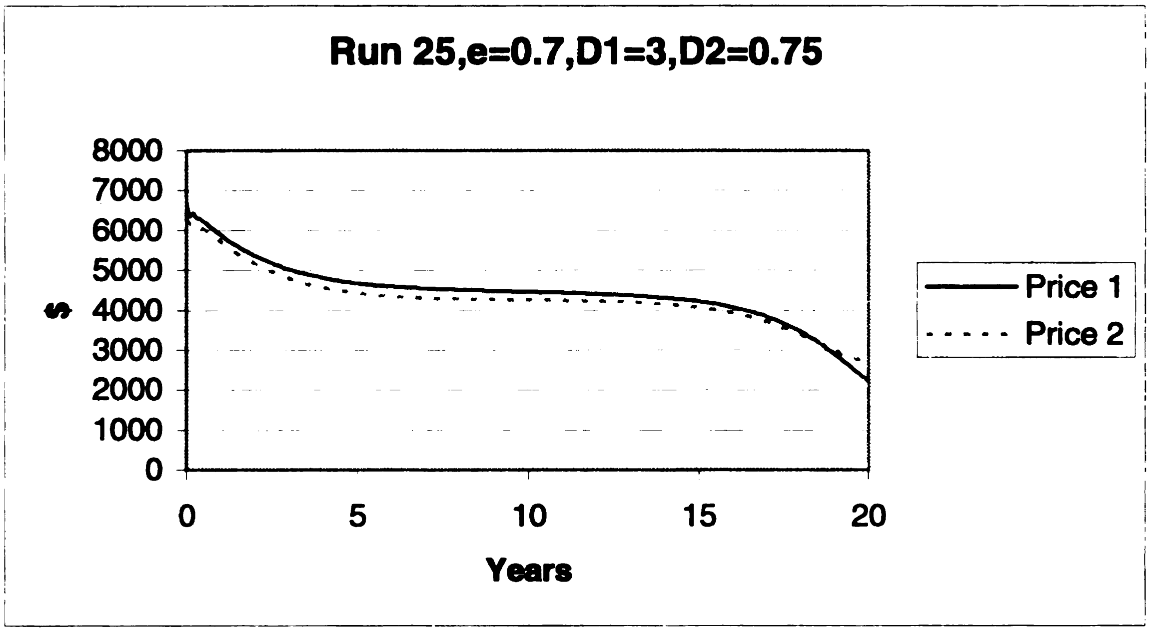


Figure 92– Run 25 Scenario 2.3

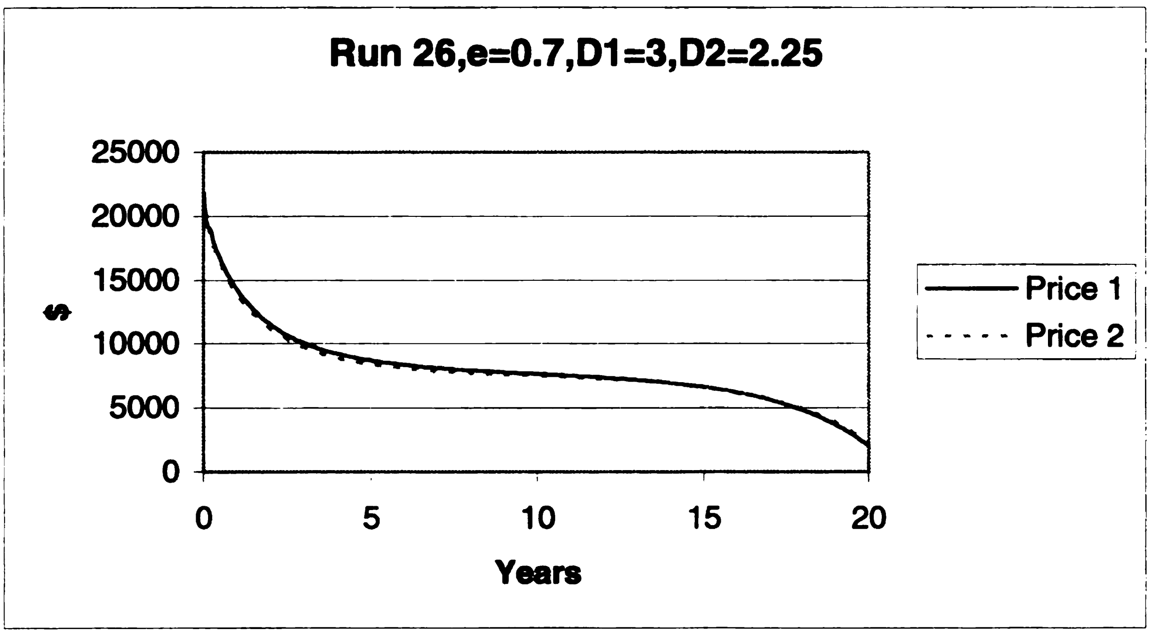


Figure 93– Run 26 Scenario 2.3

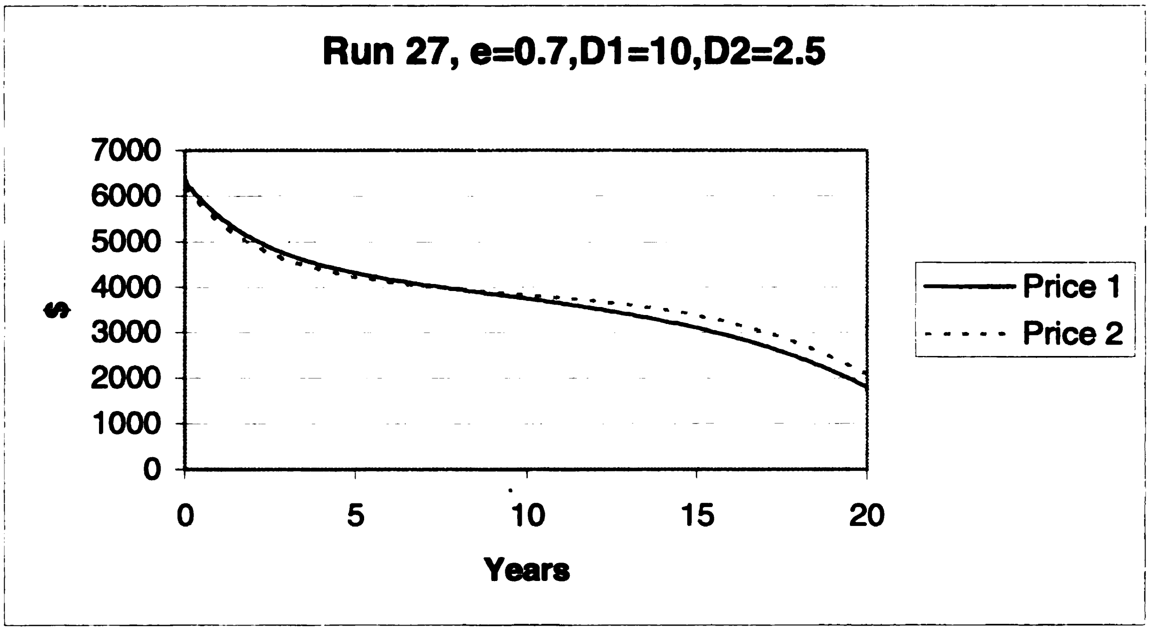


Figure 94– Run 27 Scenario 2.3

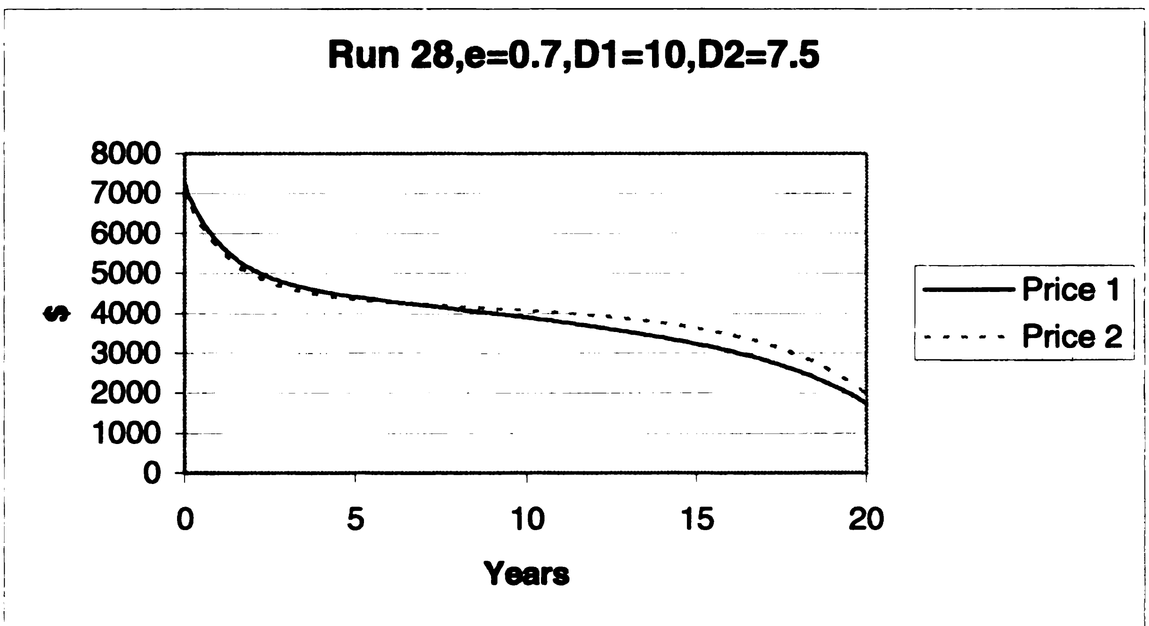


Figure 95– Run 28 Scenario 2.3

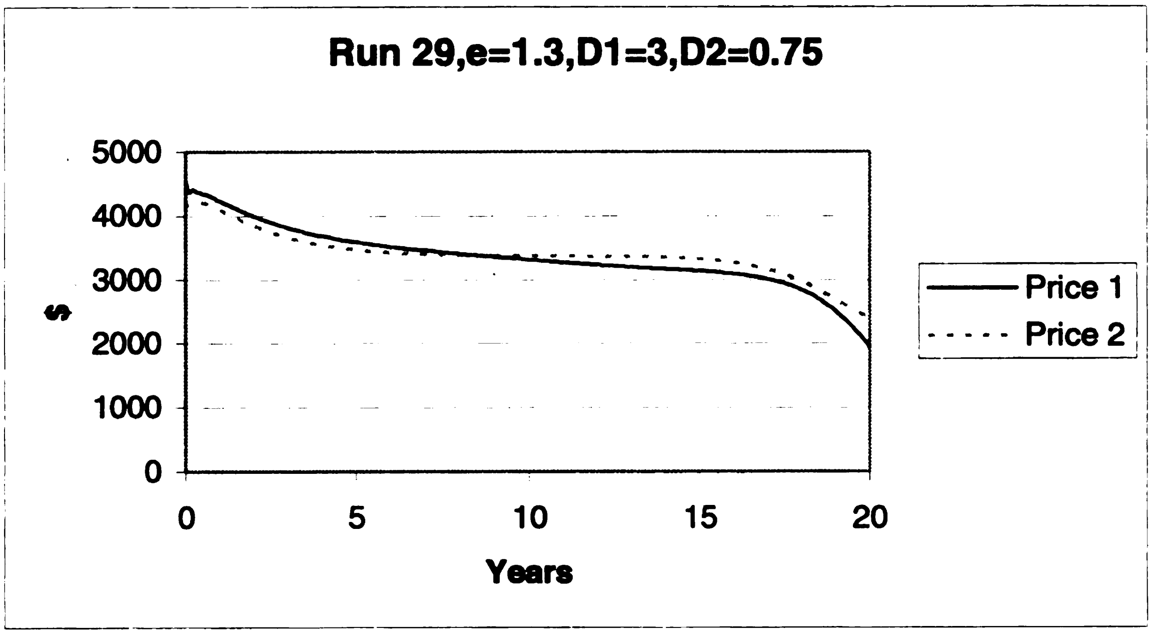


Figure 96– Run 29 Scenario 2.3

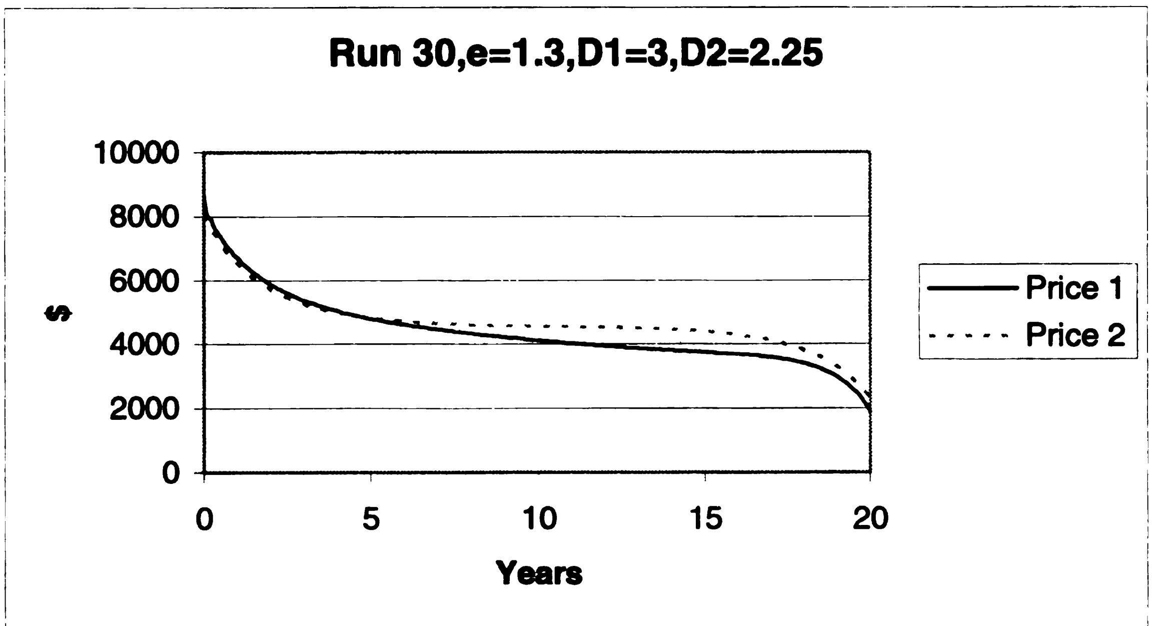


Figure 97– Run 30 Scenario 2.3

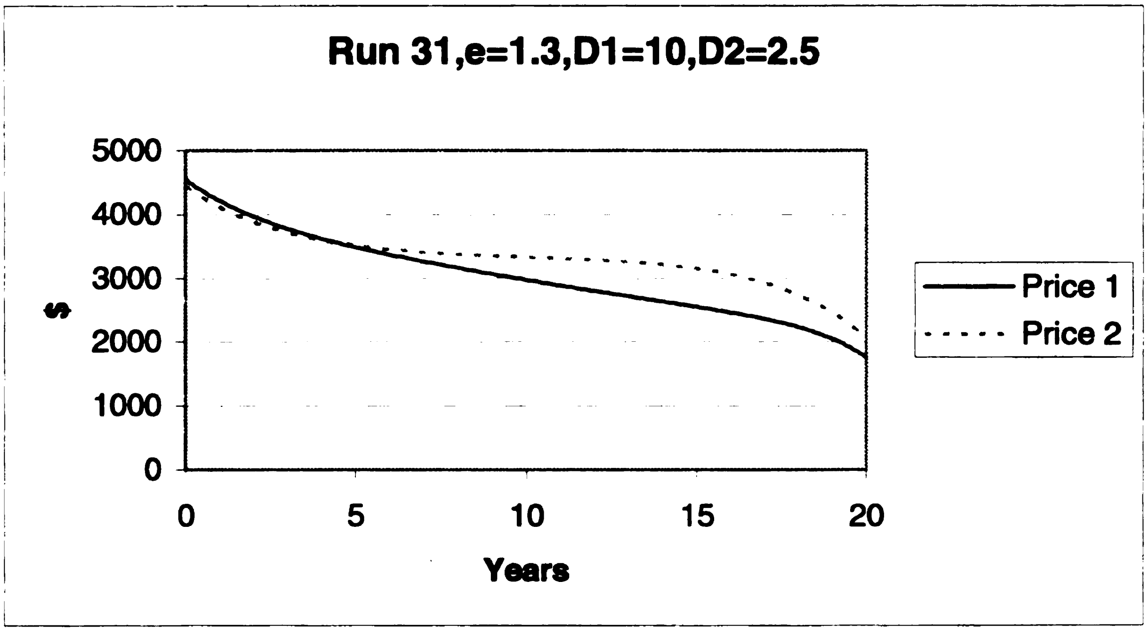


Figure 98– Run 31 Scenario 2.3

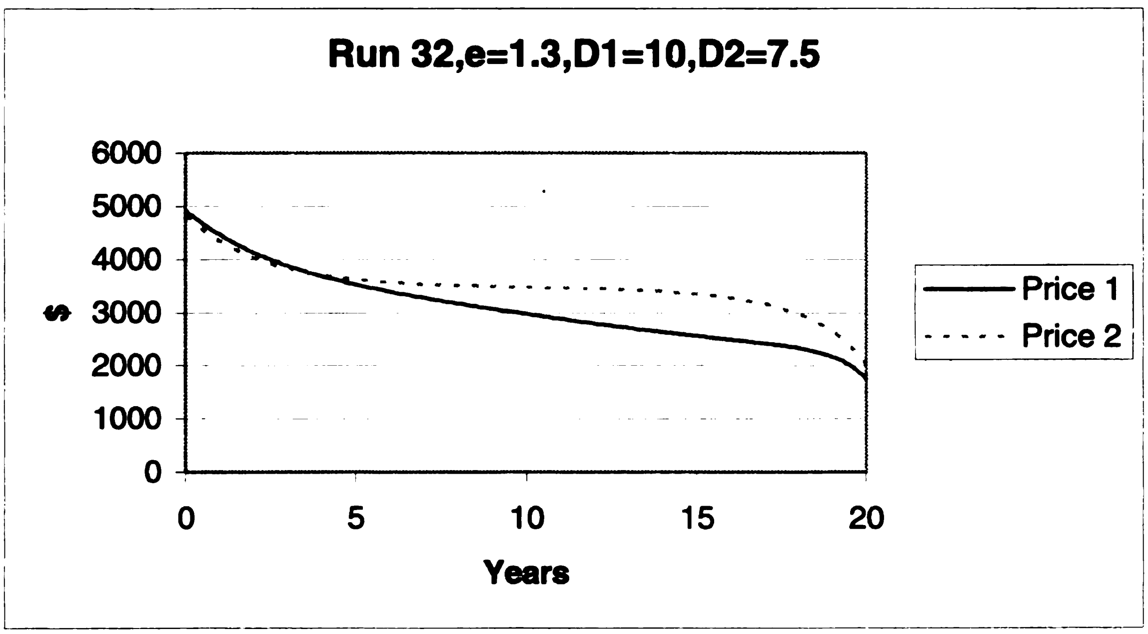


Figure 99– Run 32 Scenario 2.3

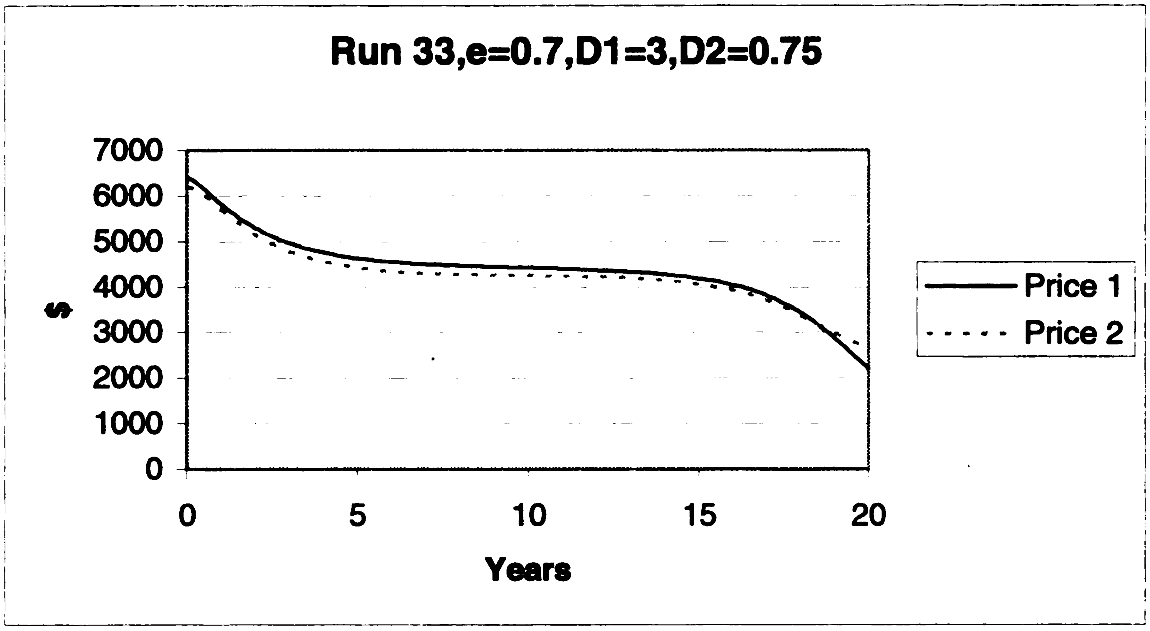


Figure 100– Run 33 Scenario 2.4

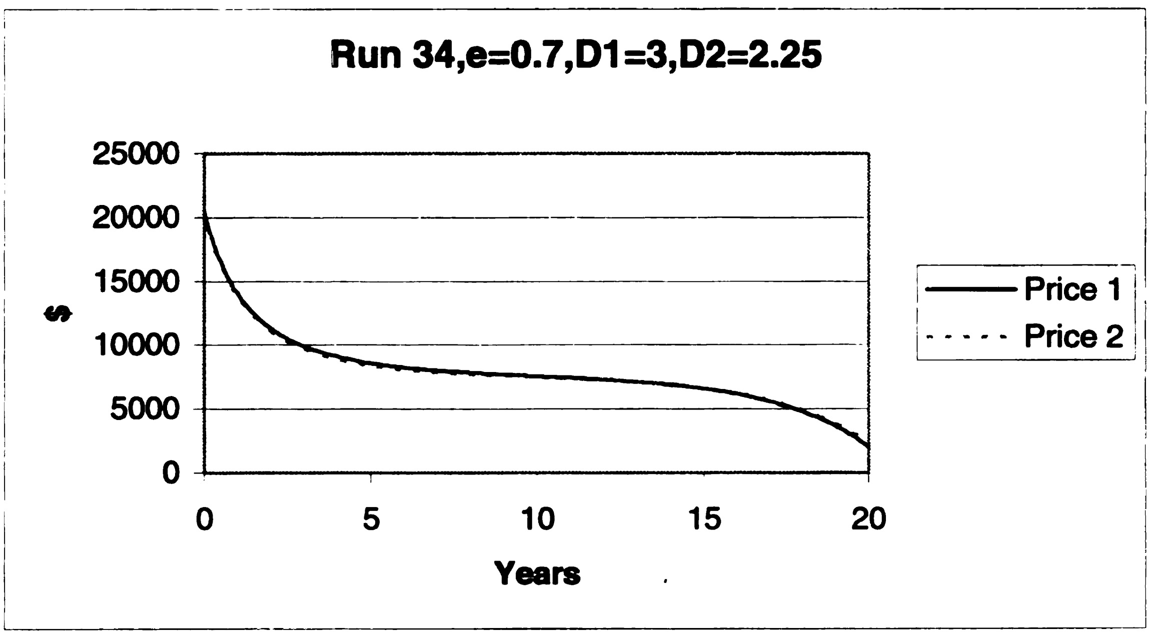


Figure 101– Run 34 Scenario 2.4

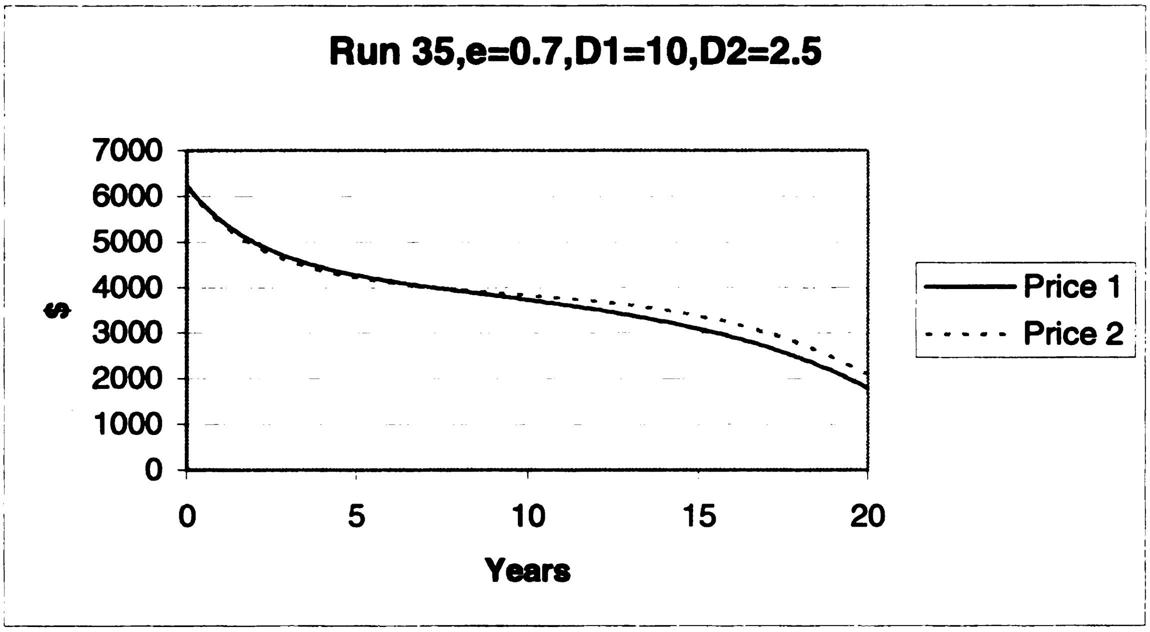


Figure 102– Run 35 Scenario 2.4

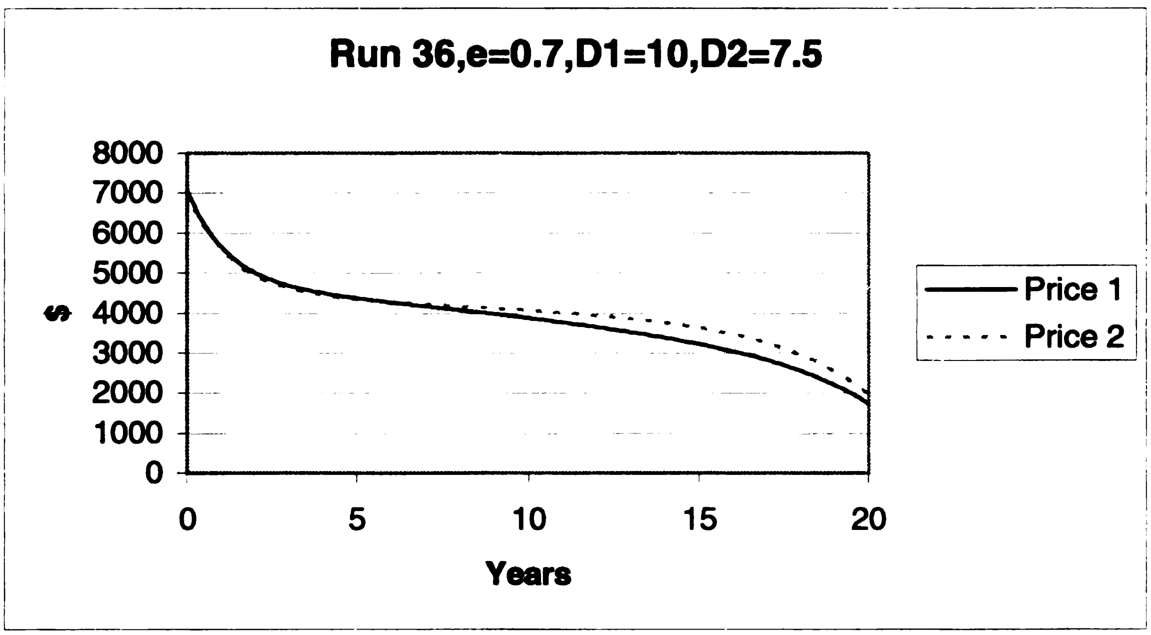


Figure 103– Run 36 Scenario 2.4

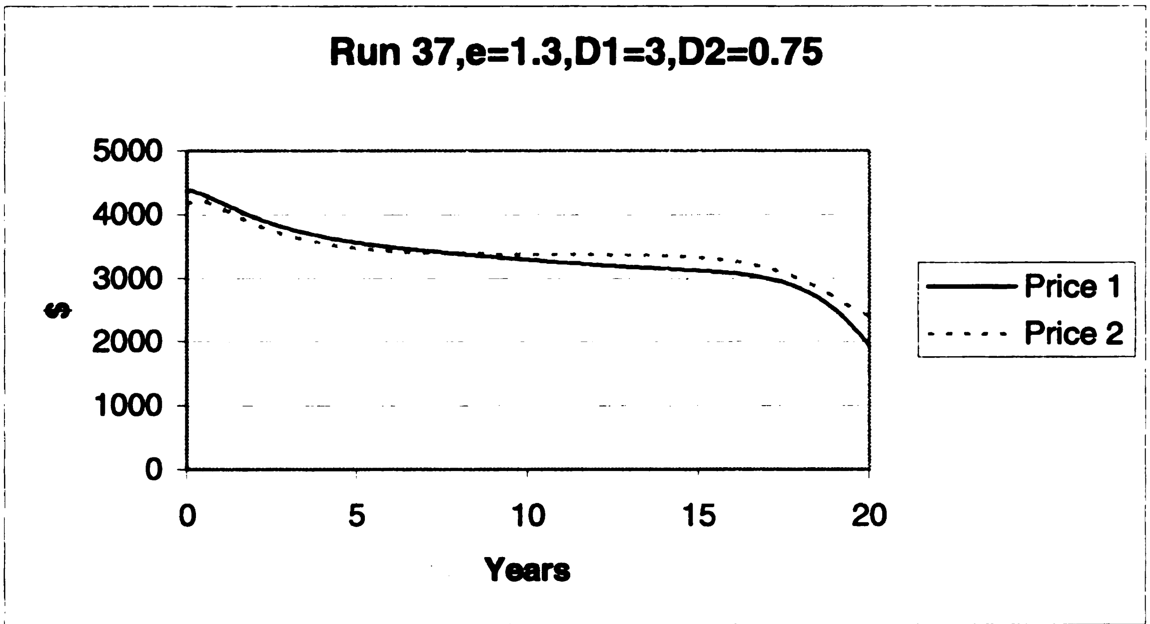


Figure 104– Run 37 Scenario 2.4

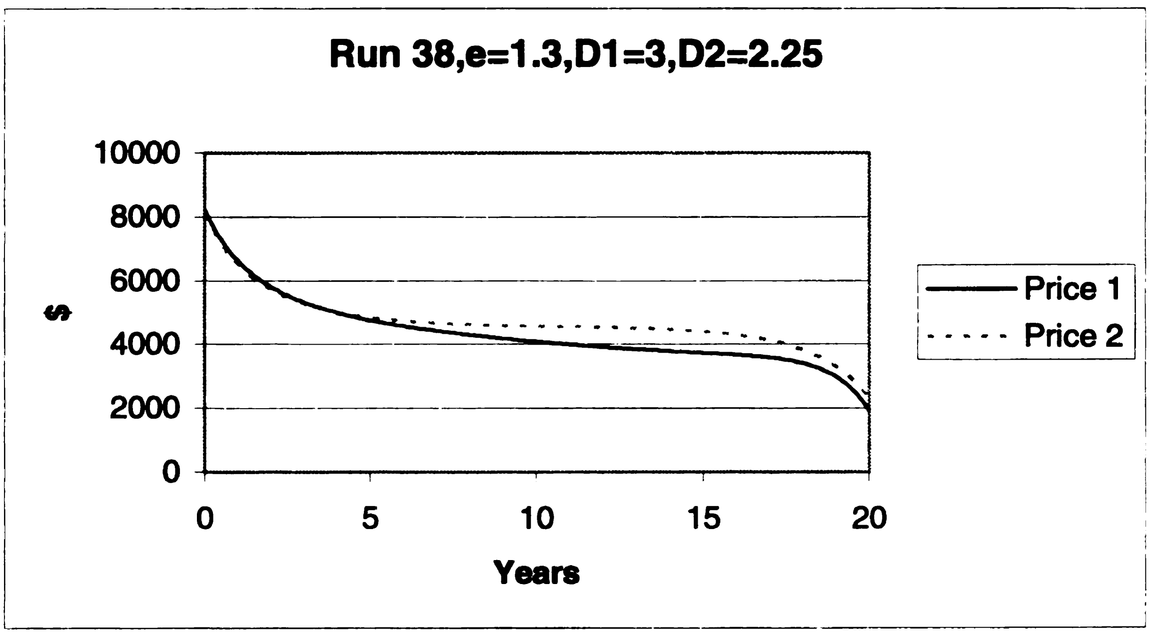


Figure 105– Run 38 Scenario 2.4

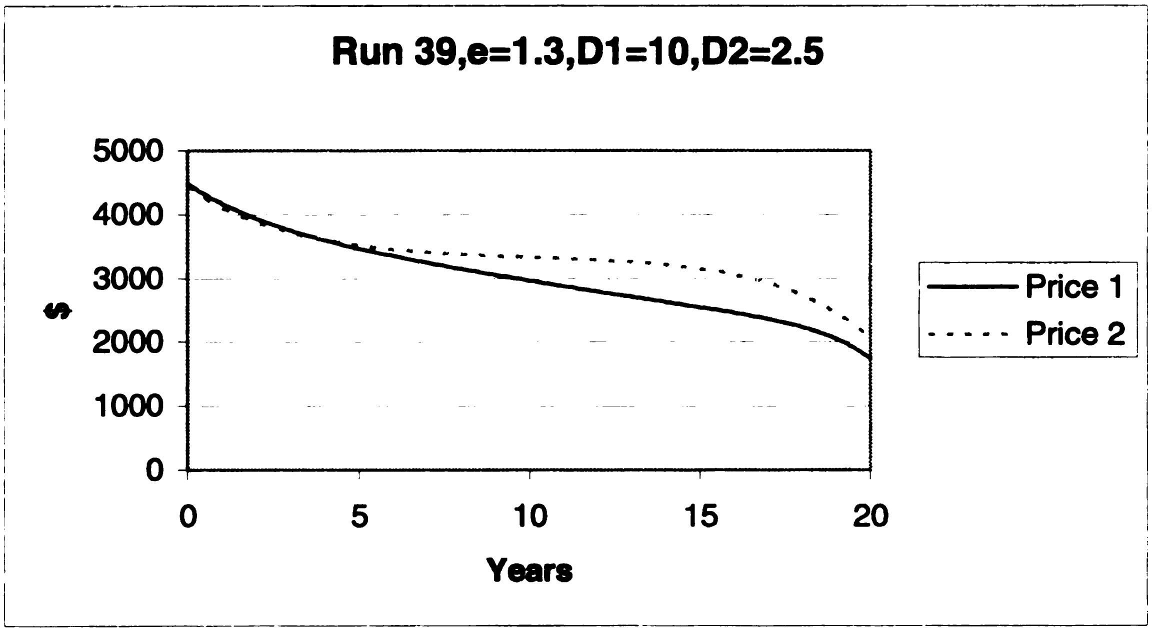


Figure 106– Run 39 Scenario 2.4

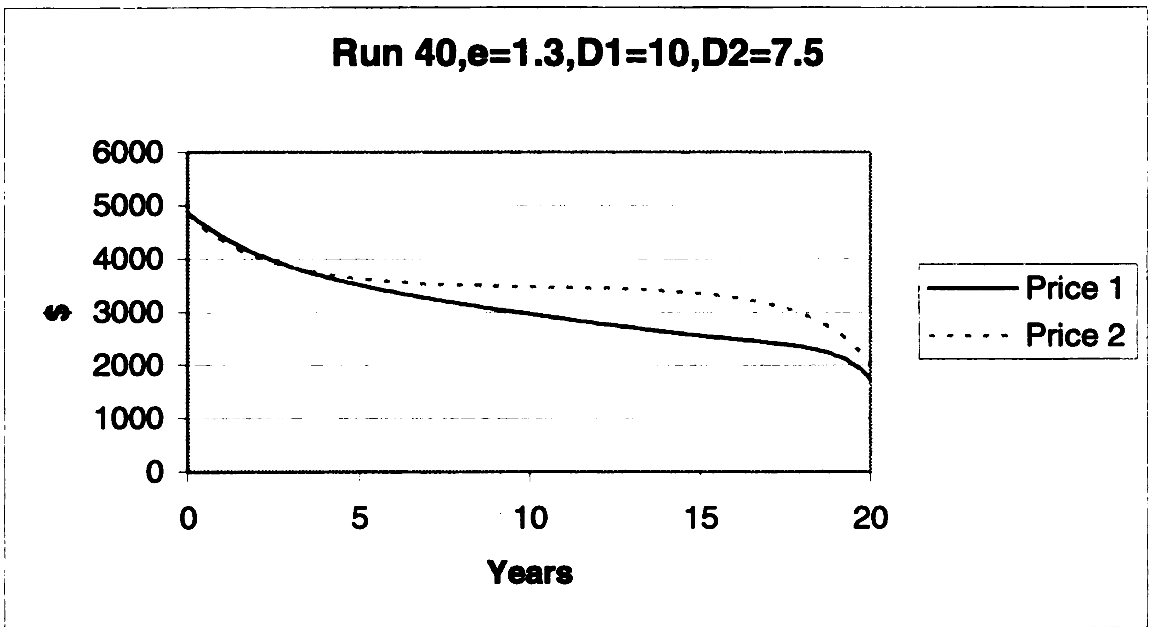


Figure 107– Run 40 Scenario 2.4

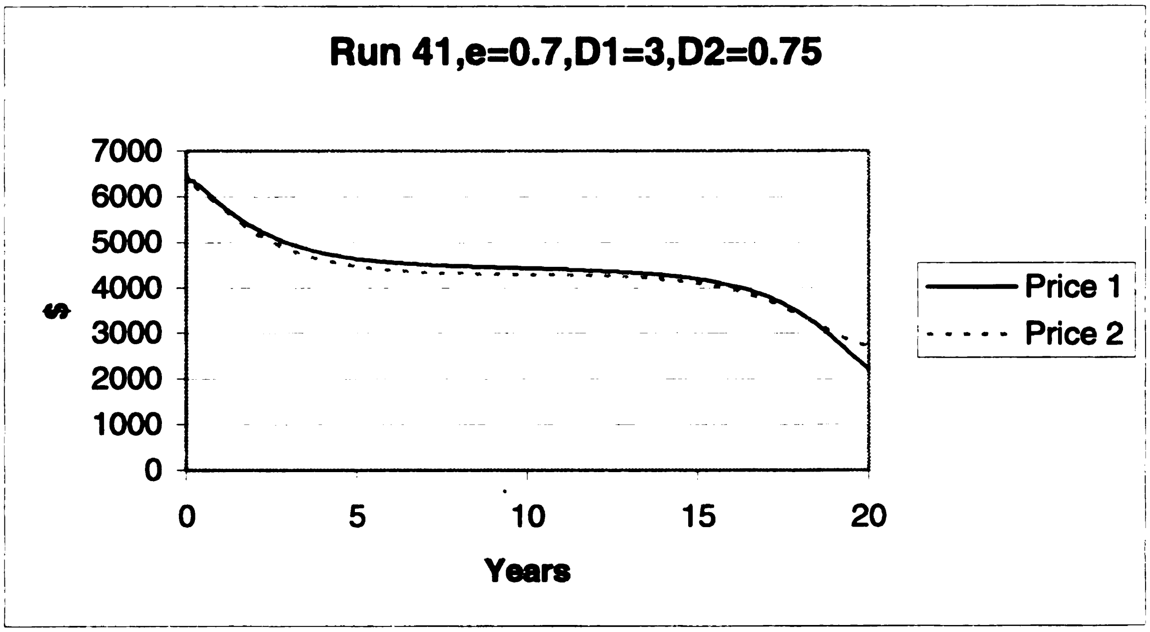


Figure 108– Run 41 Scenario 2.5

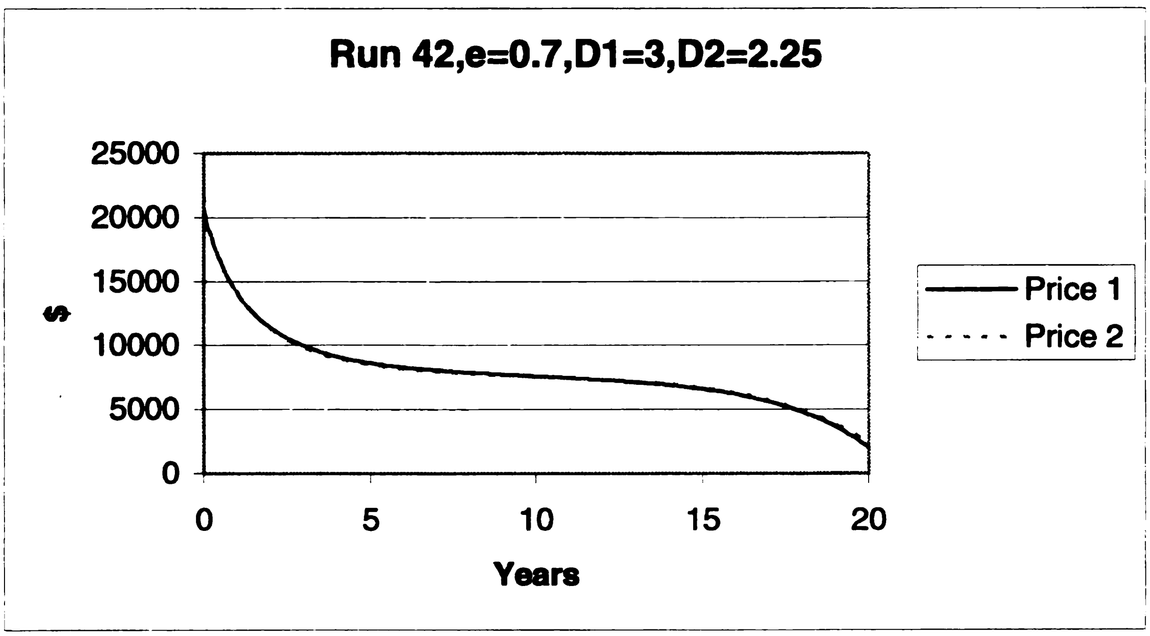


Figure 109– Run 42 Scenario 2.5

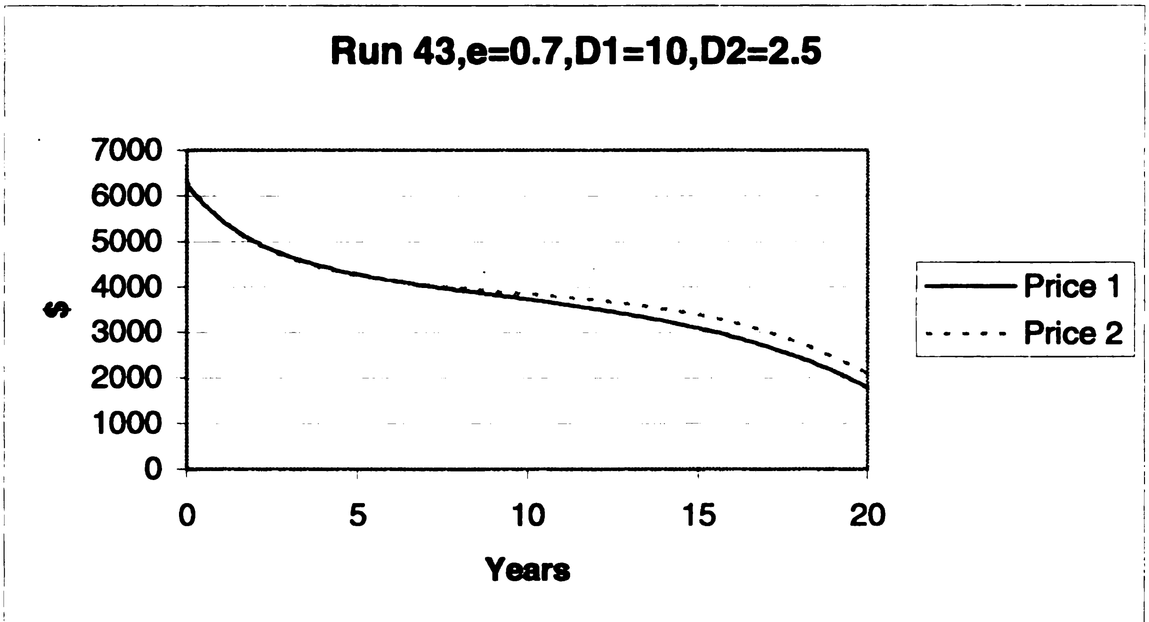


Figure 110– Run 43 Scenario 2.5

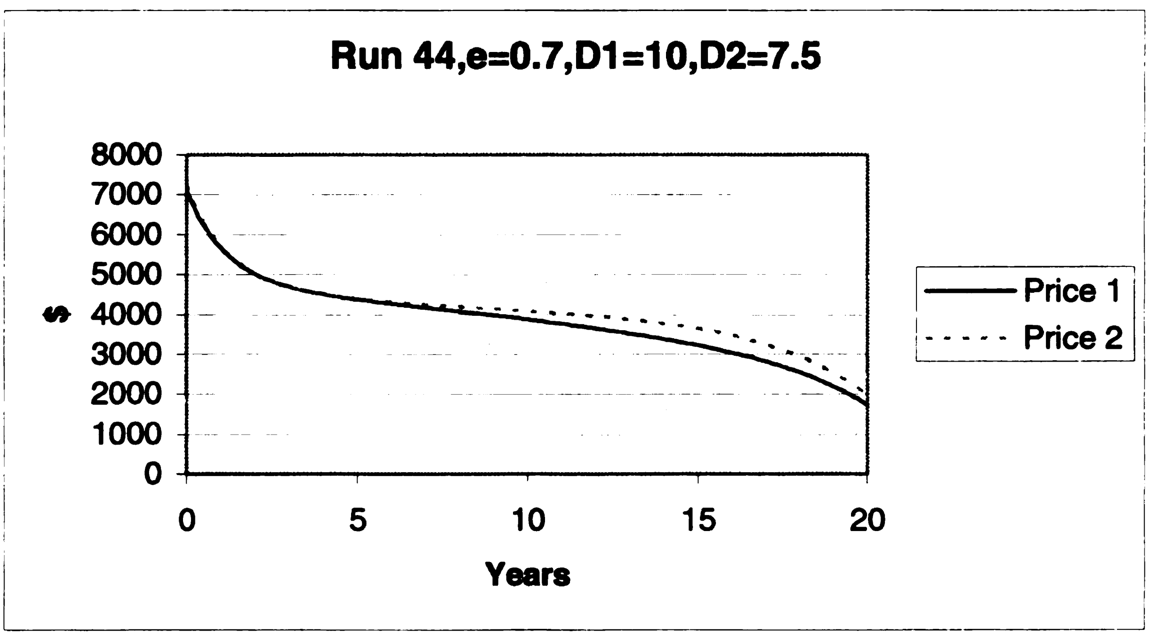


Figure 111– Run 44 Scenario 2.5

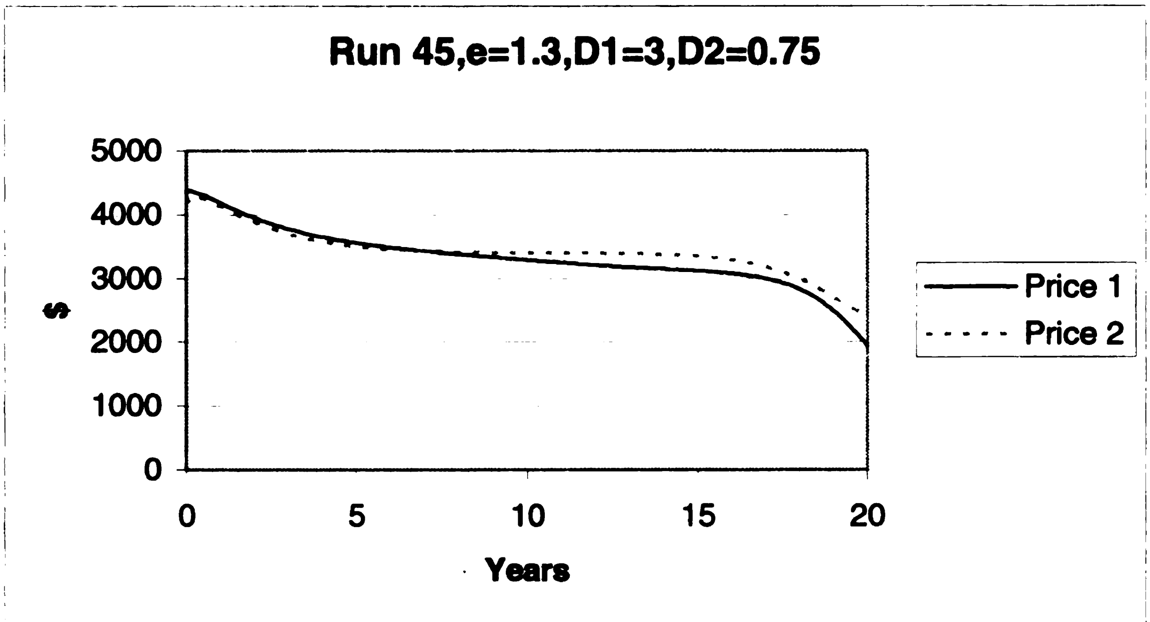


Figure 112– Run 45 Scenario 2.5

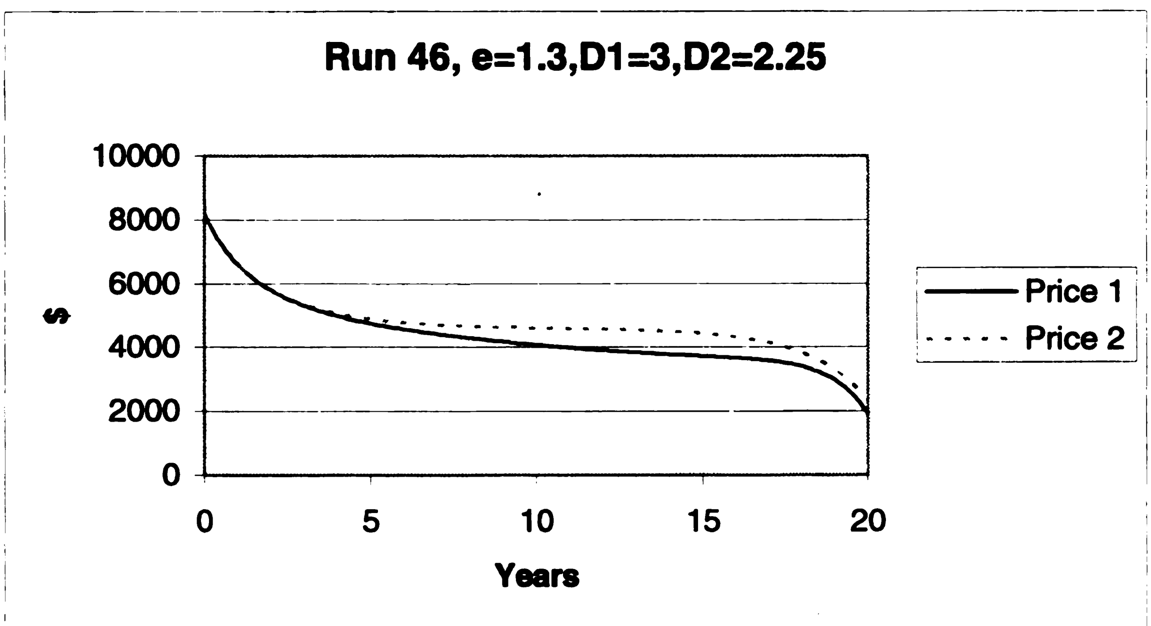


Figure 113– Run 46 Scenario 2.5

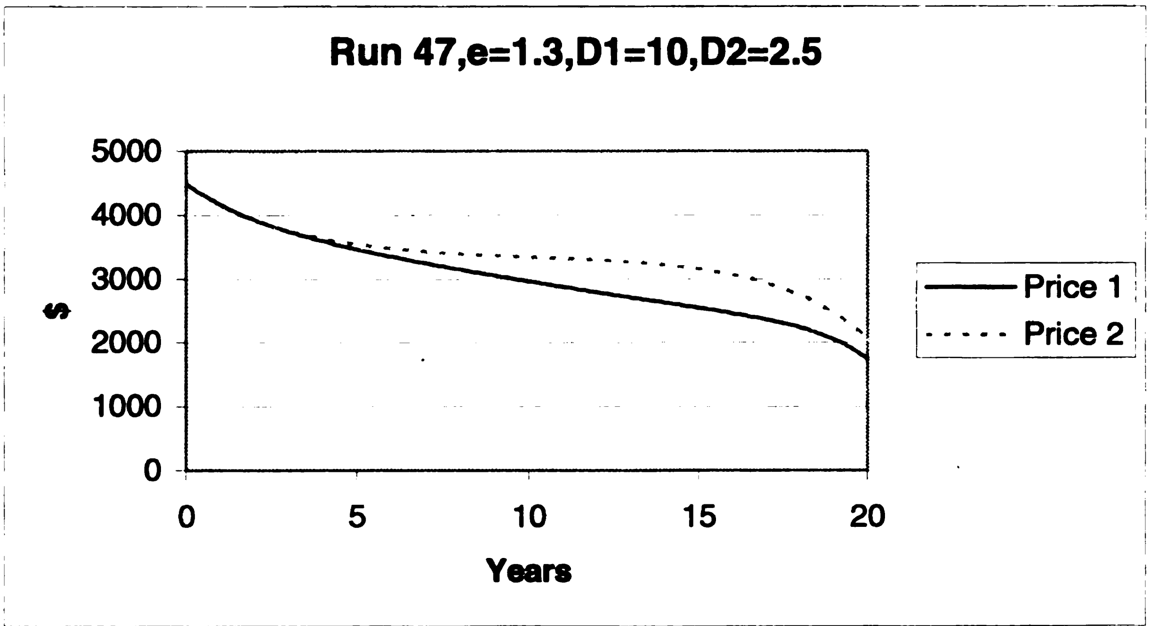


Figure 114– Run 47 Scenario 2.5

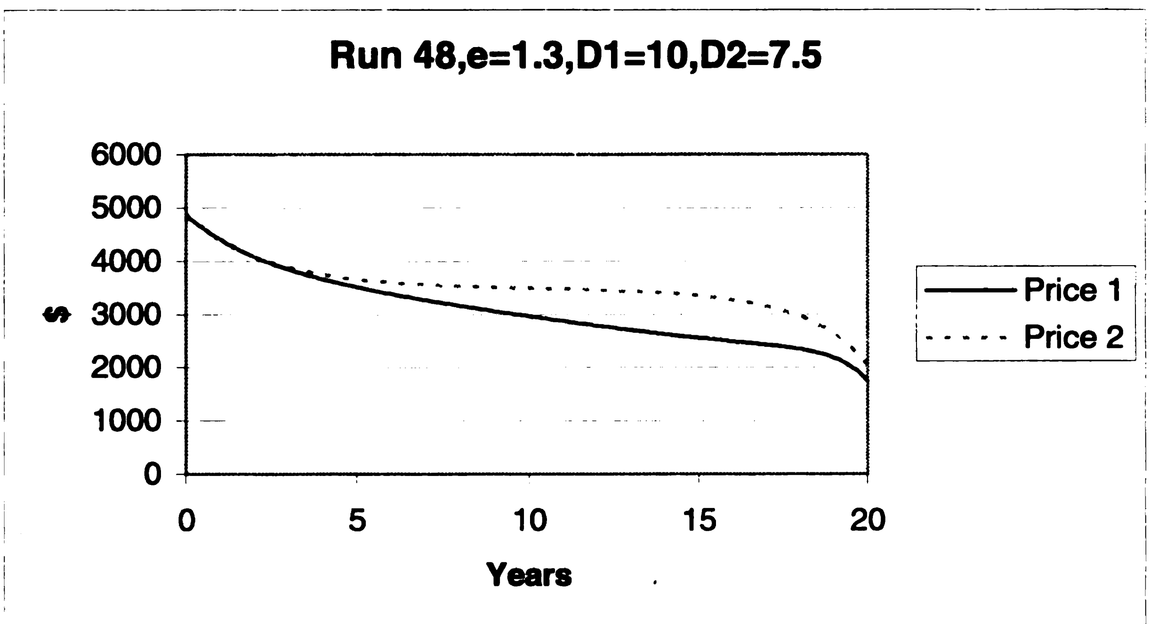


Figure 115 – Run 48 Scenario 2.5

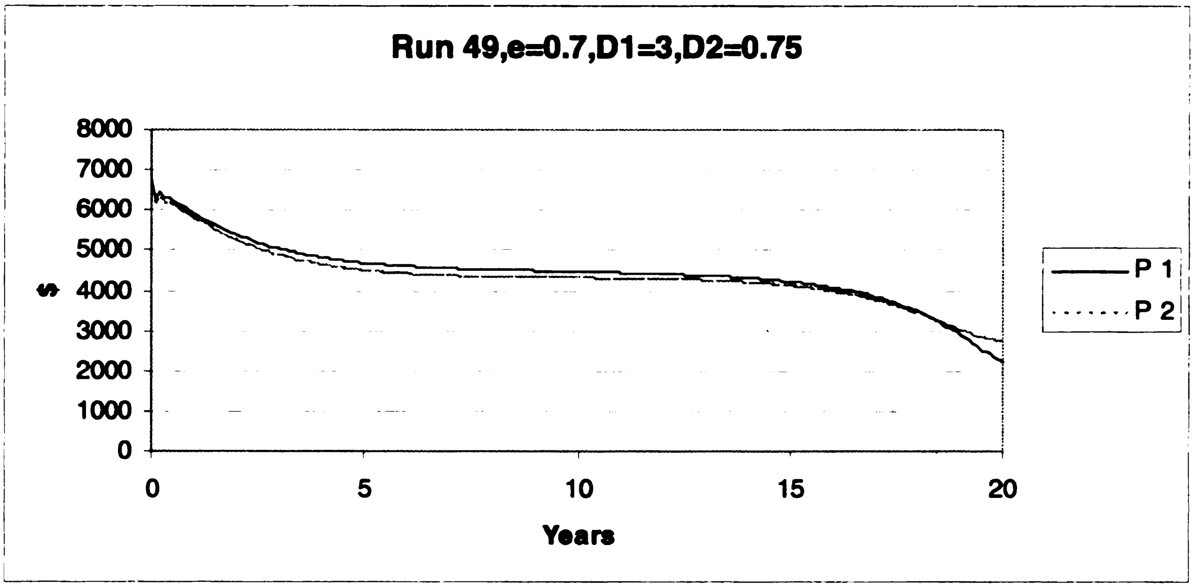


Figure 116 – Run 49 Scenario 2.6

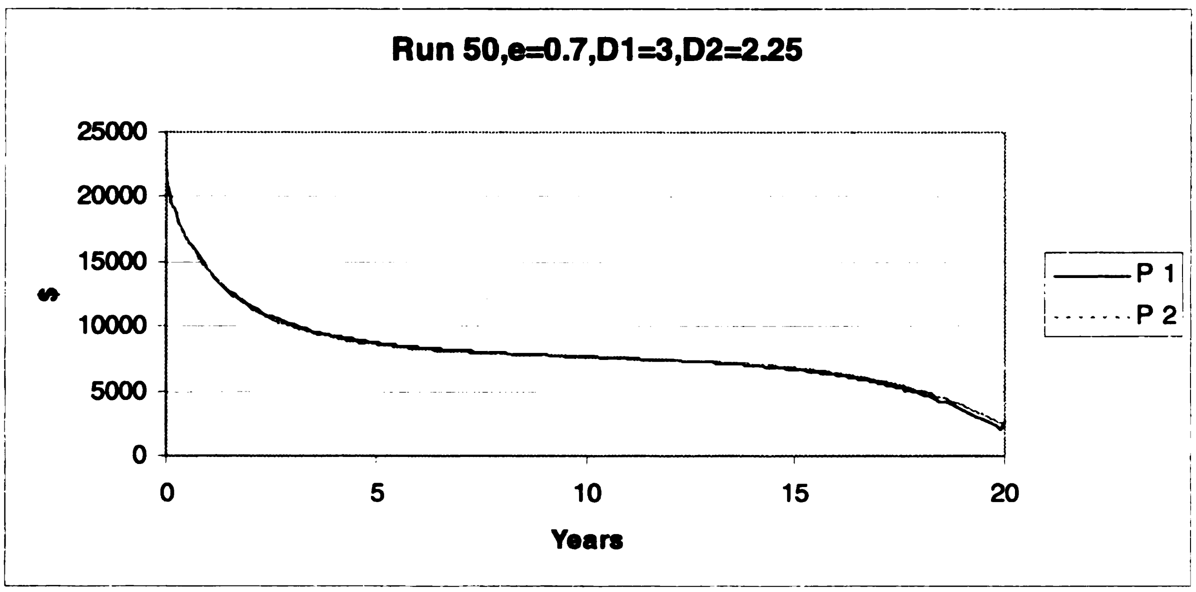


Figure 117 – Run 50 Scenario 2.6

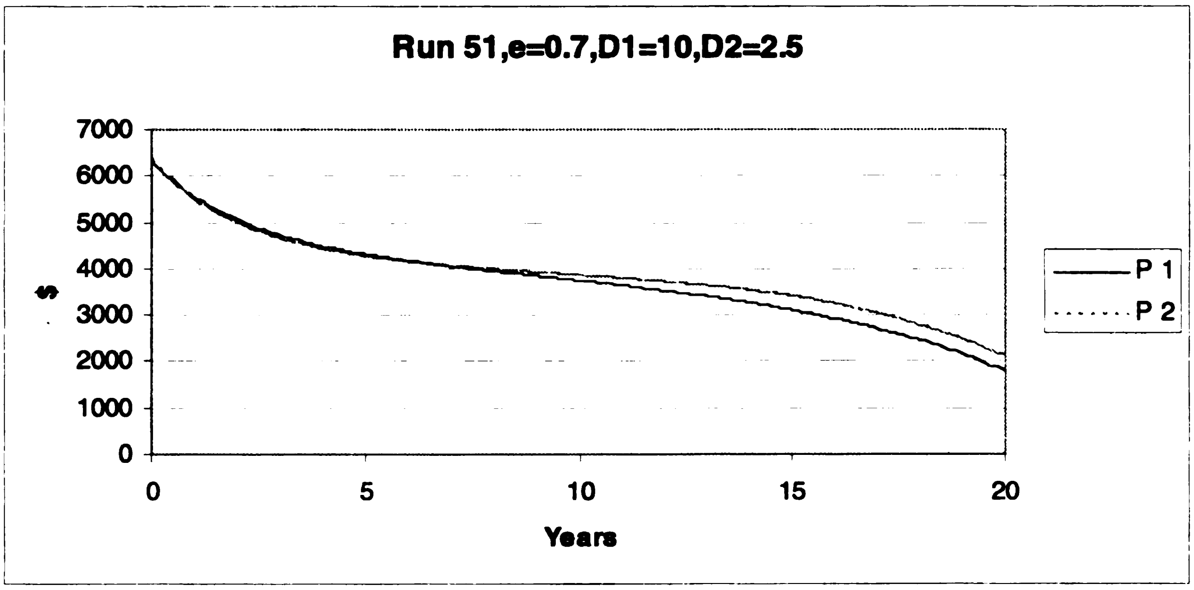


Figure 118 – Run 51 Scenario 2.6

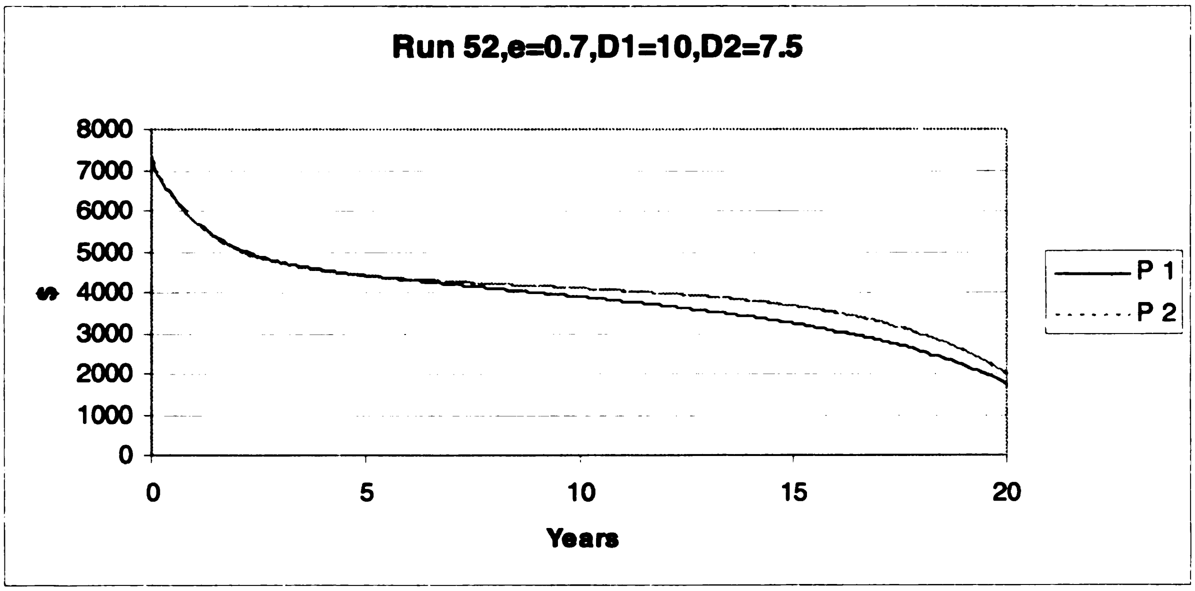


Figure 119 – Run 52 Scenario 2.6

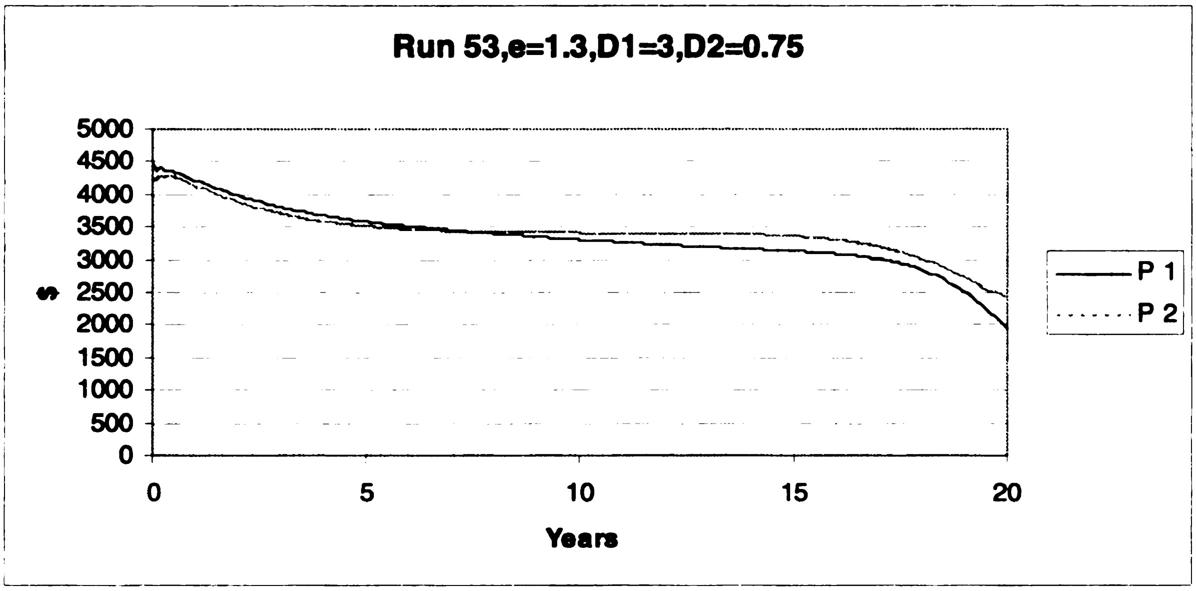


Figure 120 – Run 53 Scenario 2.6

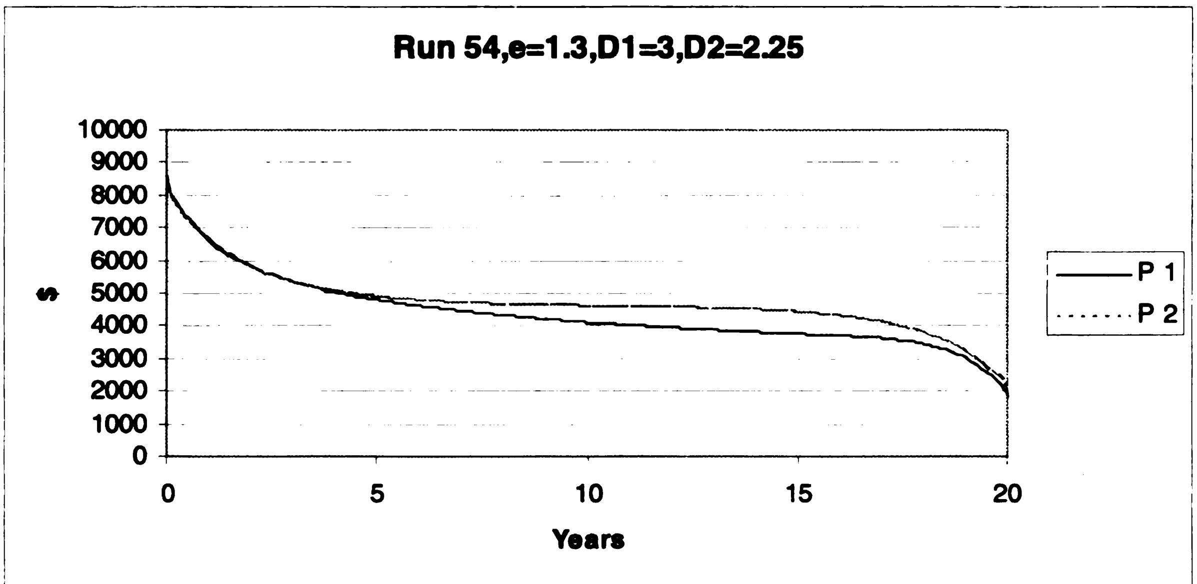


Figure 121 – Run 54 Scenario 2.6

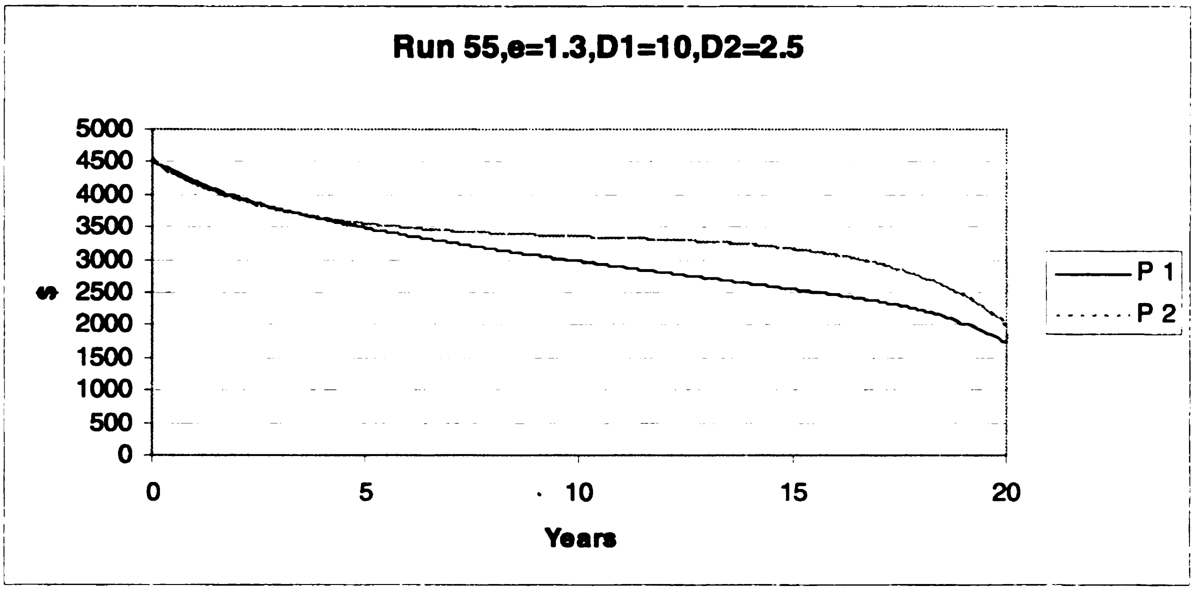


Figure 122– Run 55 Scenario 2.6

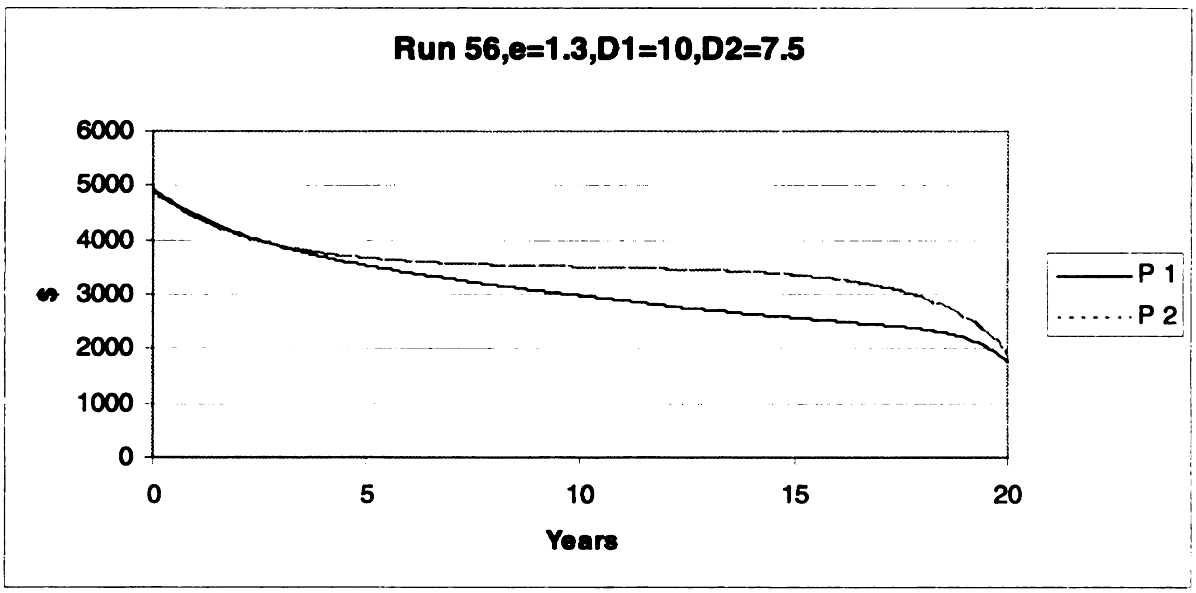


Figure 123 – Run 56 Scenario 2.6

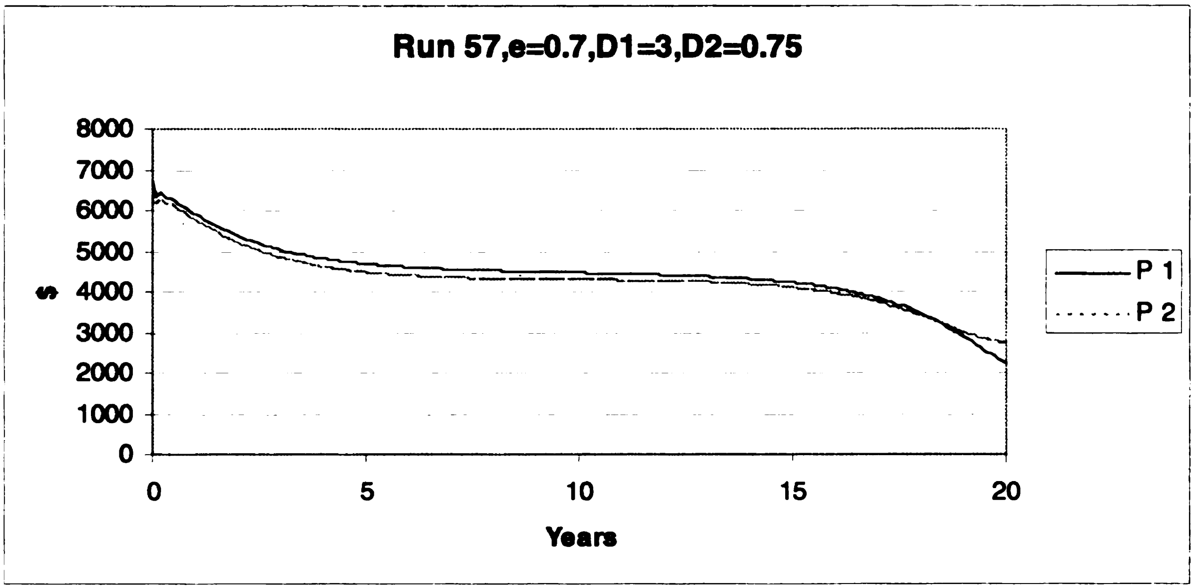


Figure 124 – Run 57 Scenario 2.7

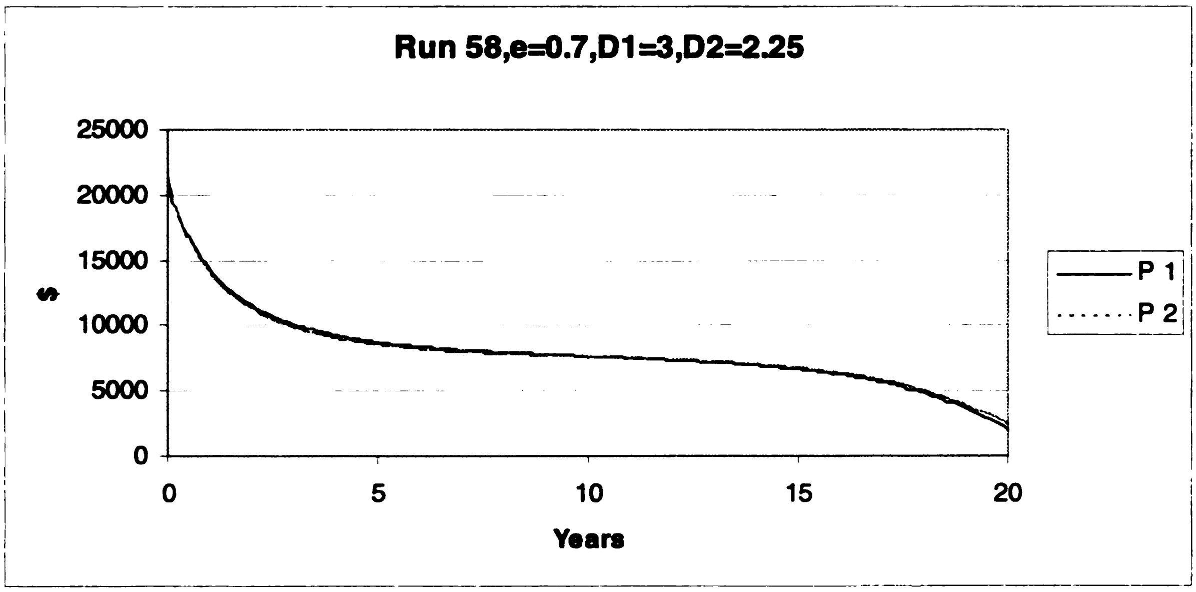


Figure 125 – Run 58 Scenario 2.7

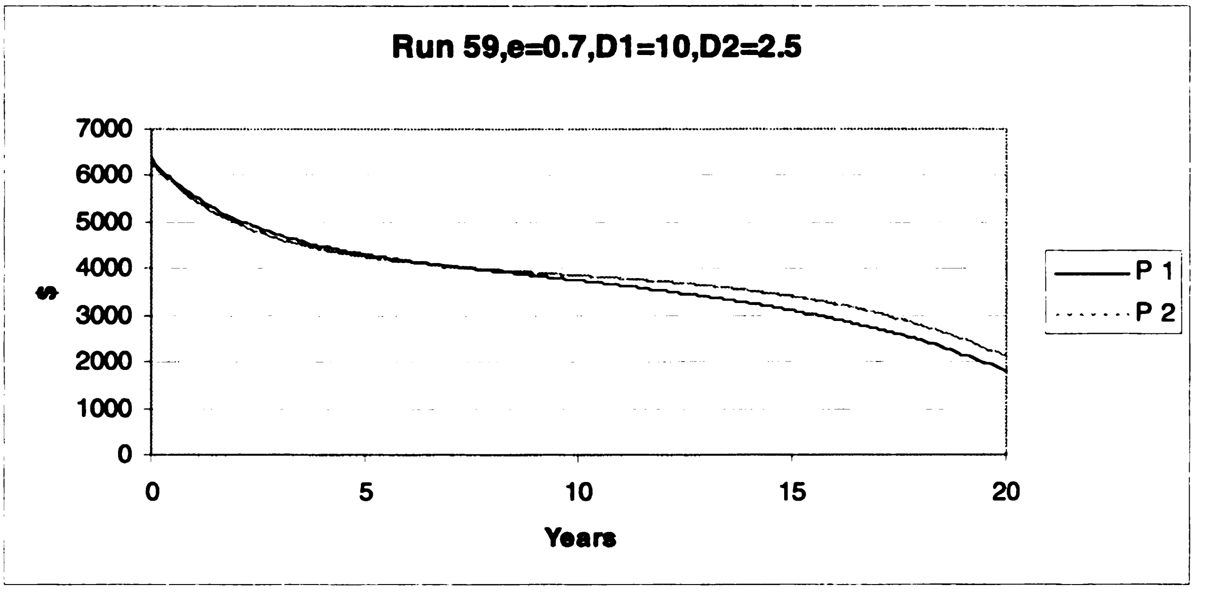


Figure 126 – Run 59 Scenario 2.7

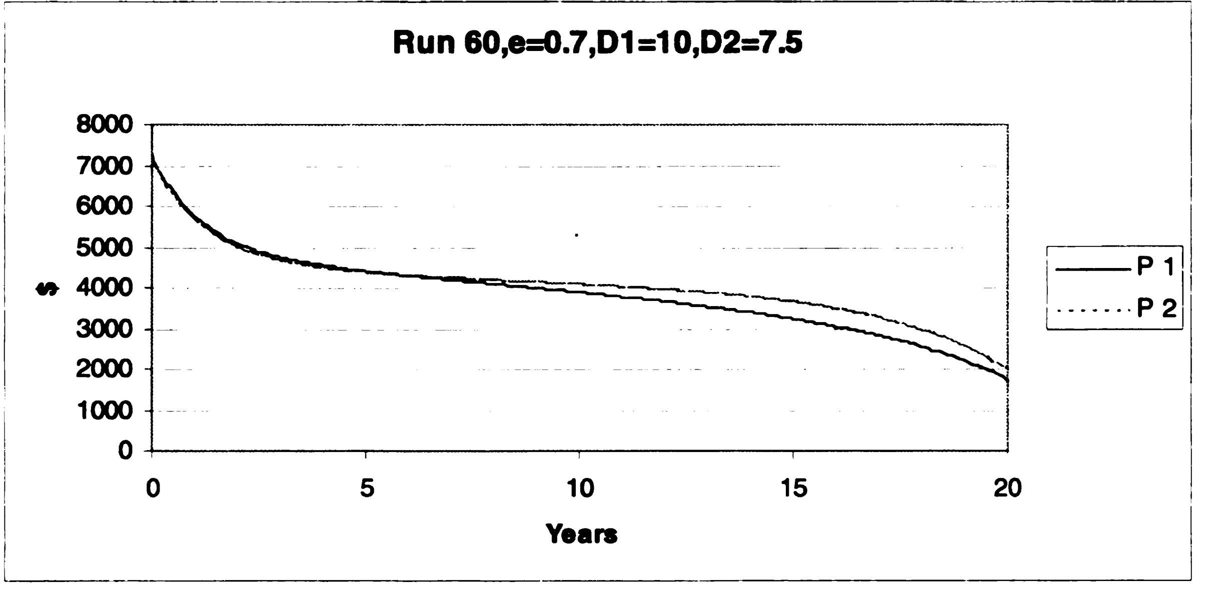


Figure 127 – Run 60 Scenario 2.7

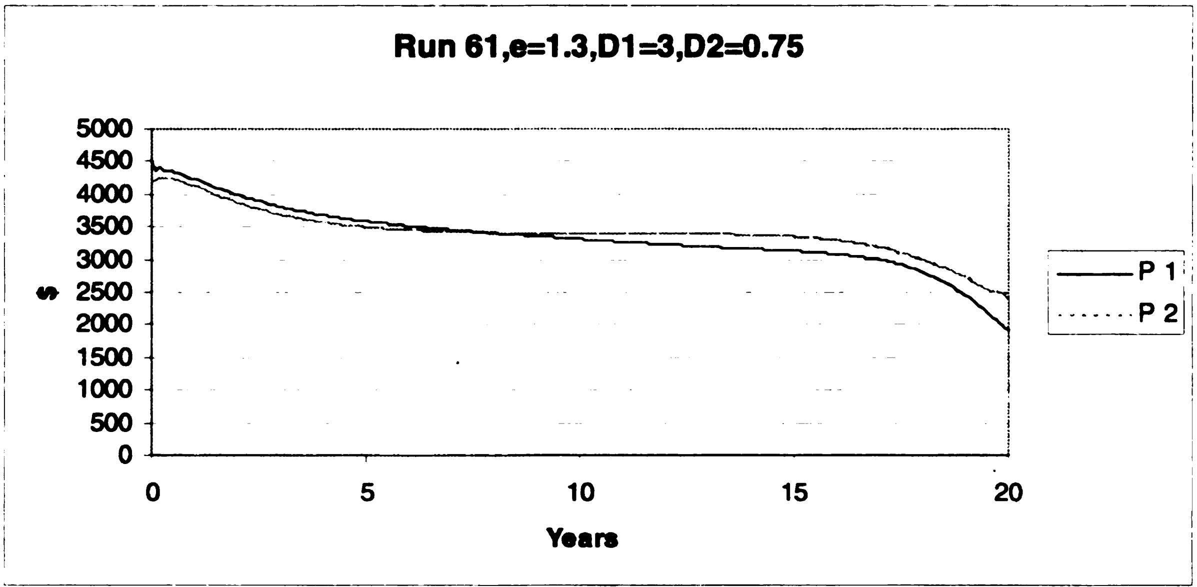


Figure 128 – Run 61 Scenario 2.7

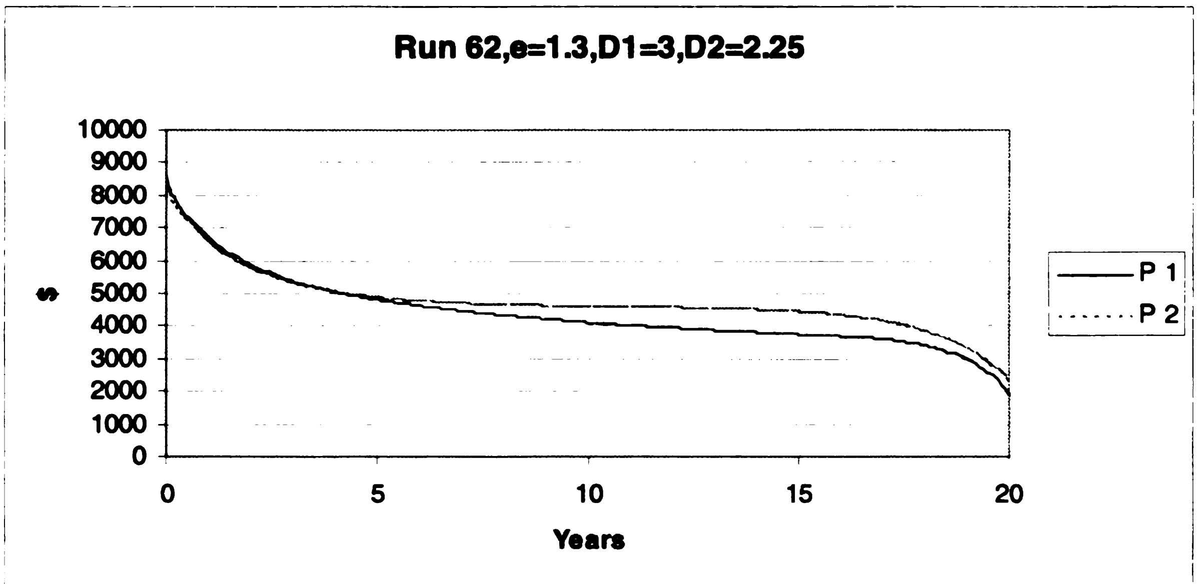


Figure 129 – Run 62 Scenario 2.7

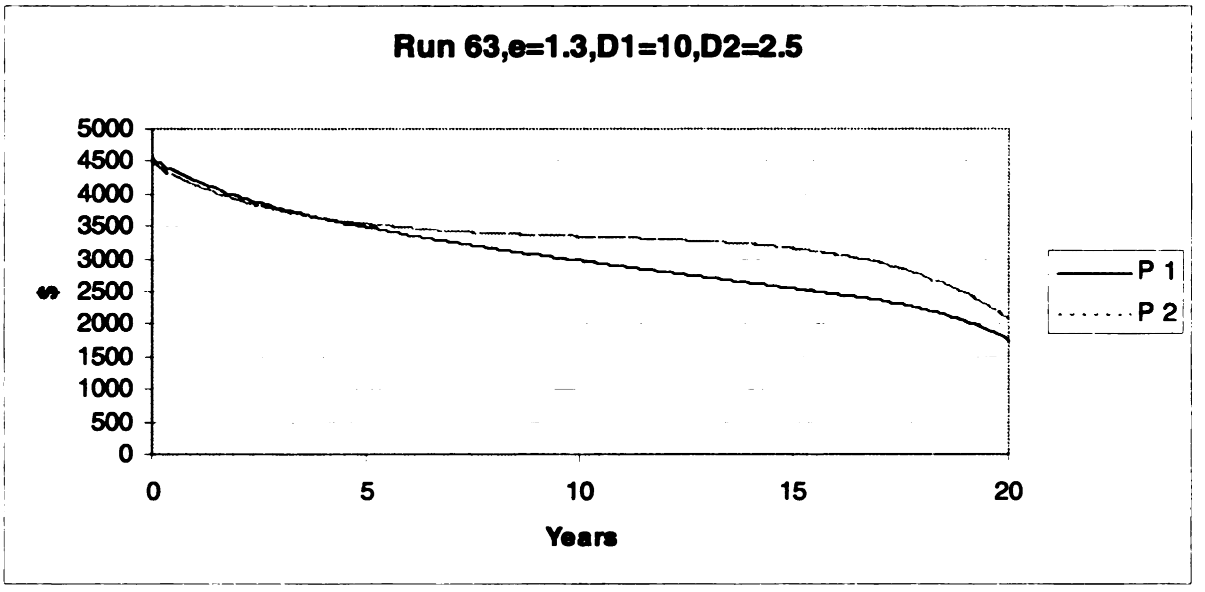


Figure 130 – Run 63 Scenario 2.7

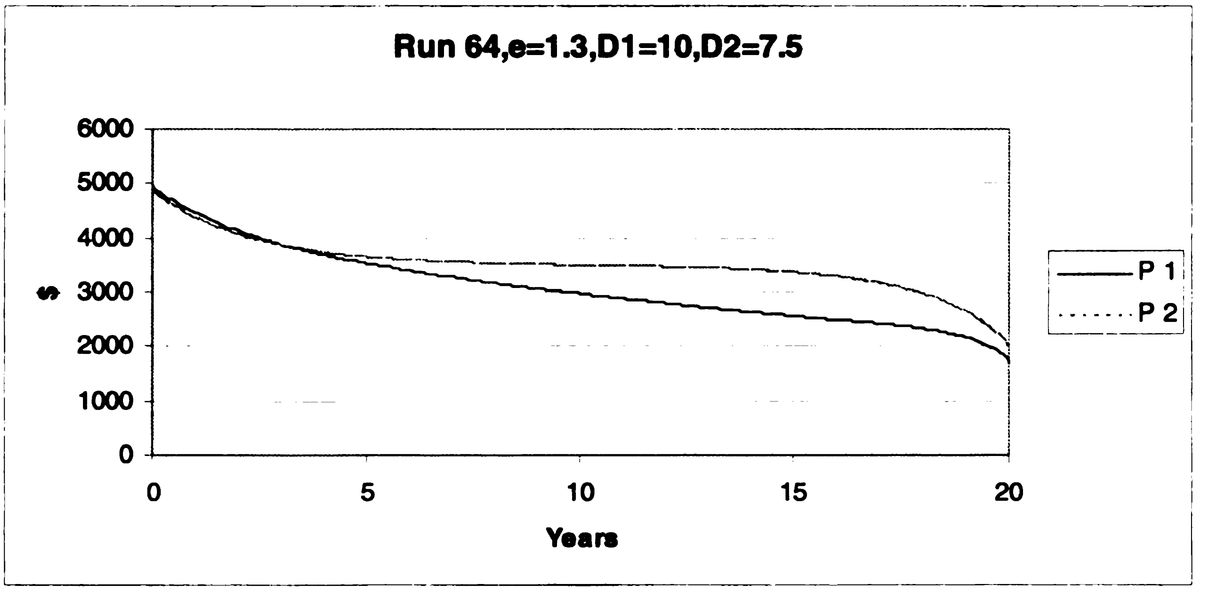


Figure 131 – Run 64 Scenario 2.7

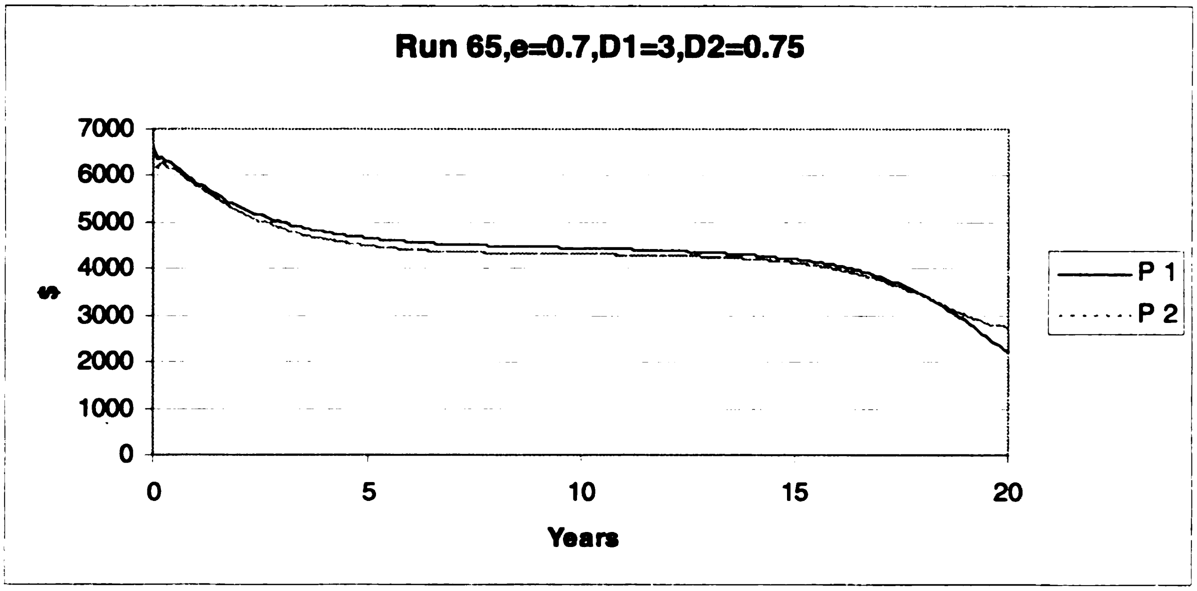


Figure 132 – Run 65 Scenario 2.8

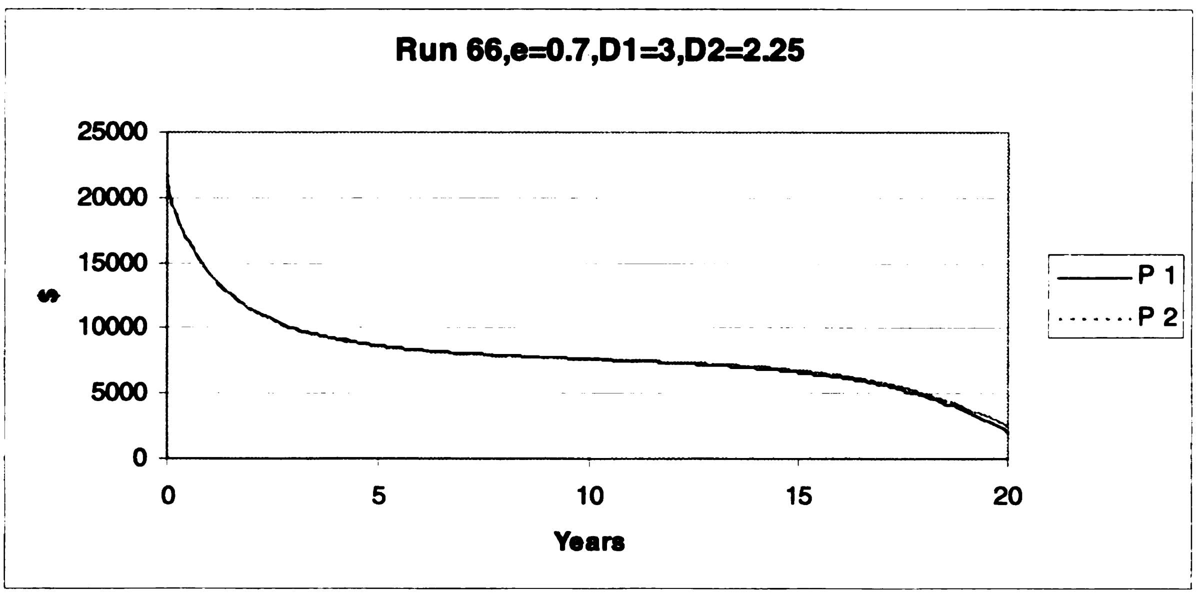


Figure 133 – Run 66 Scenario 2.8

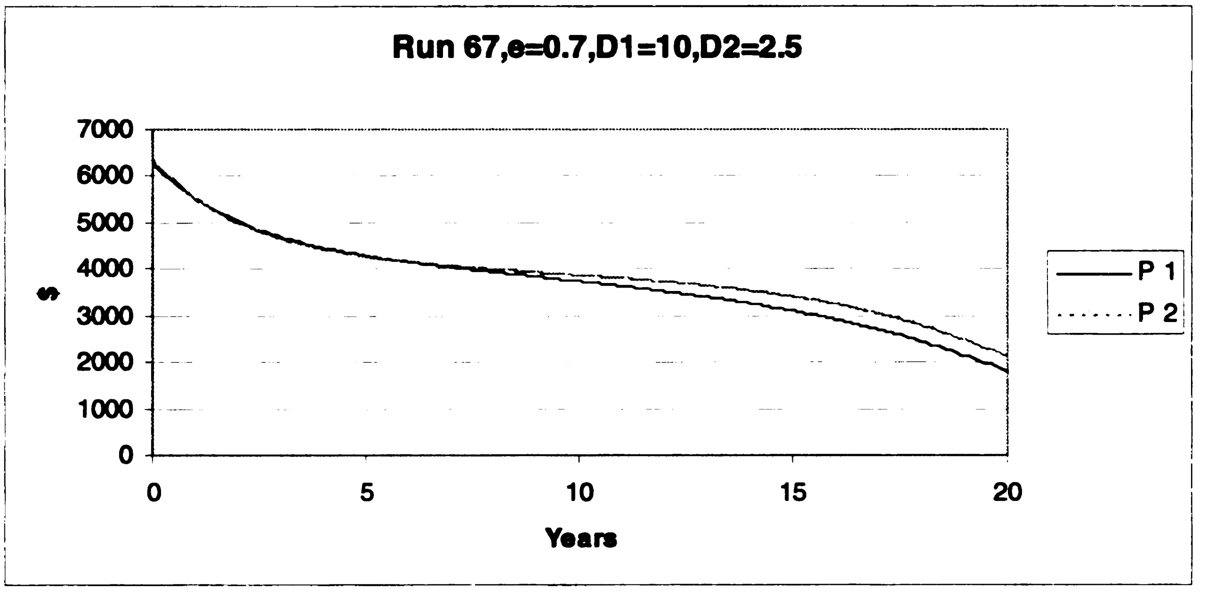


Figure 134 – Run 67 Scenario 2.8

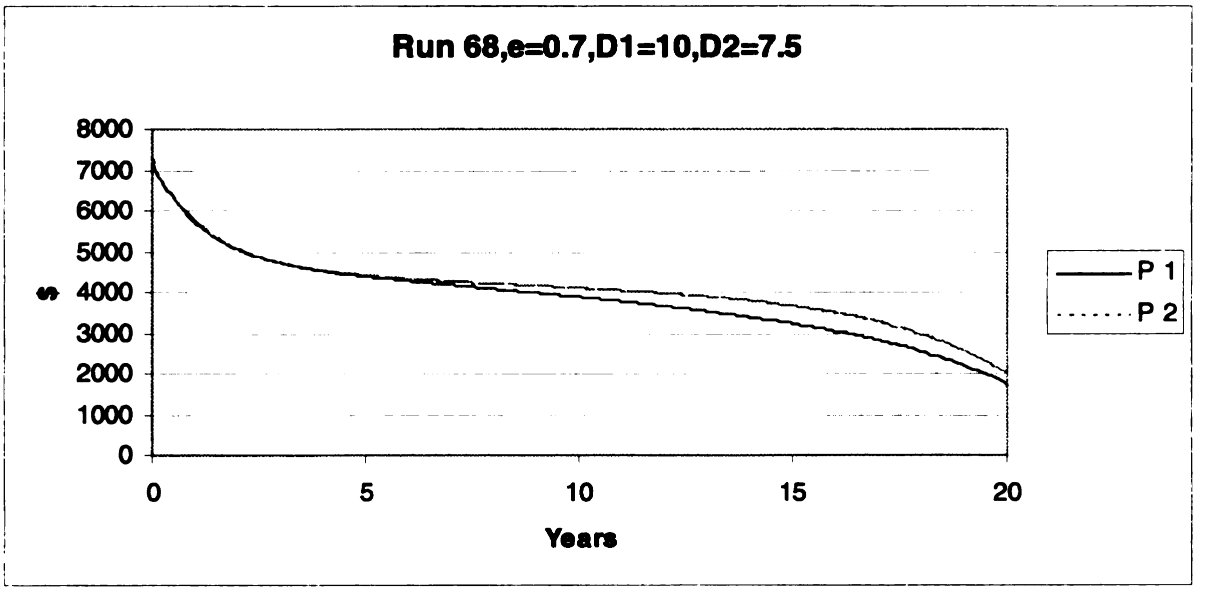


Figure 135 – Run 68 Scenario 2.8

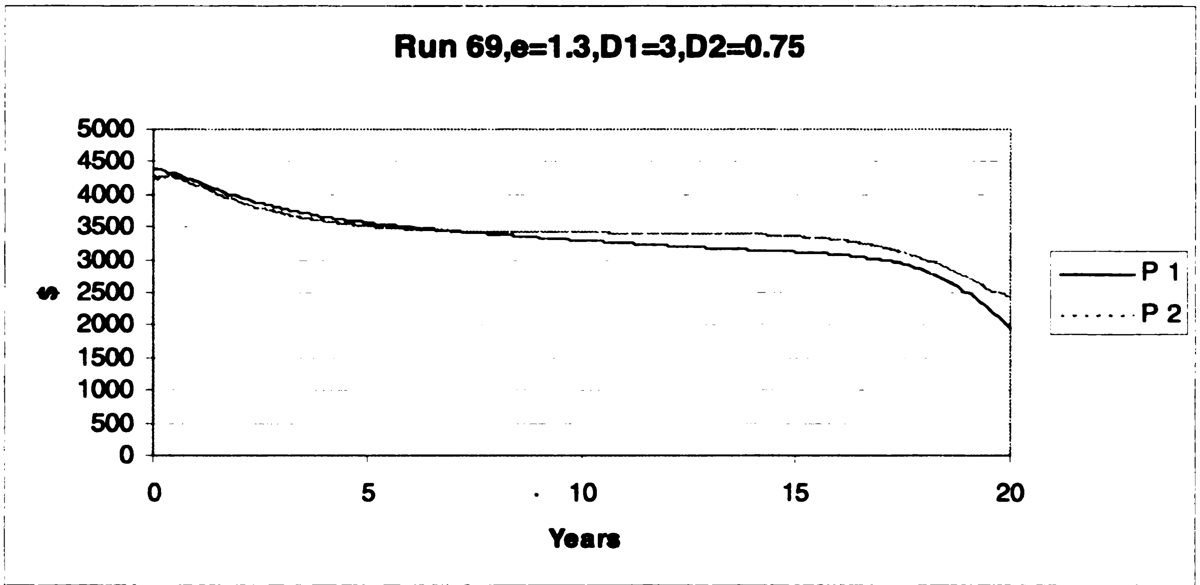


Figure 136 – Run 69 Scenario 2.8

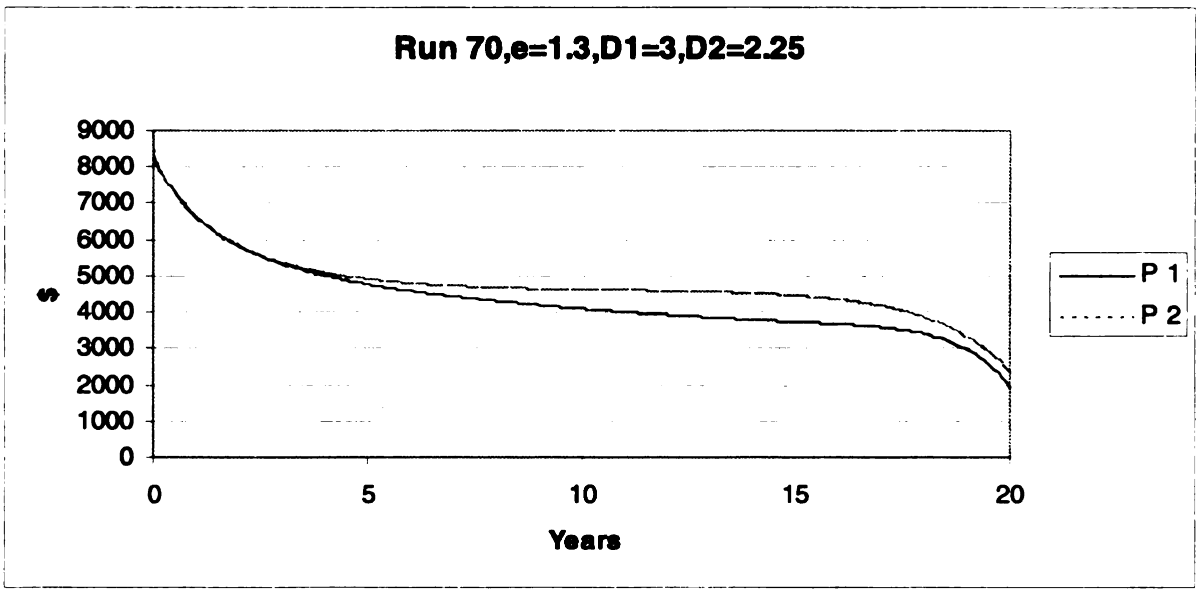


Figure 137 – Run 70 Scenario 2.8

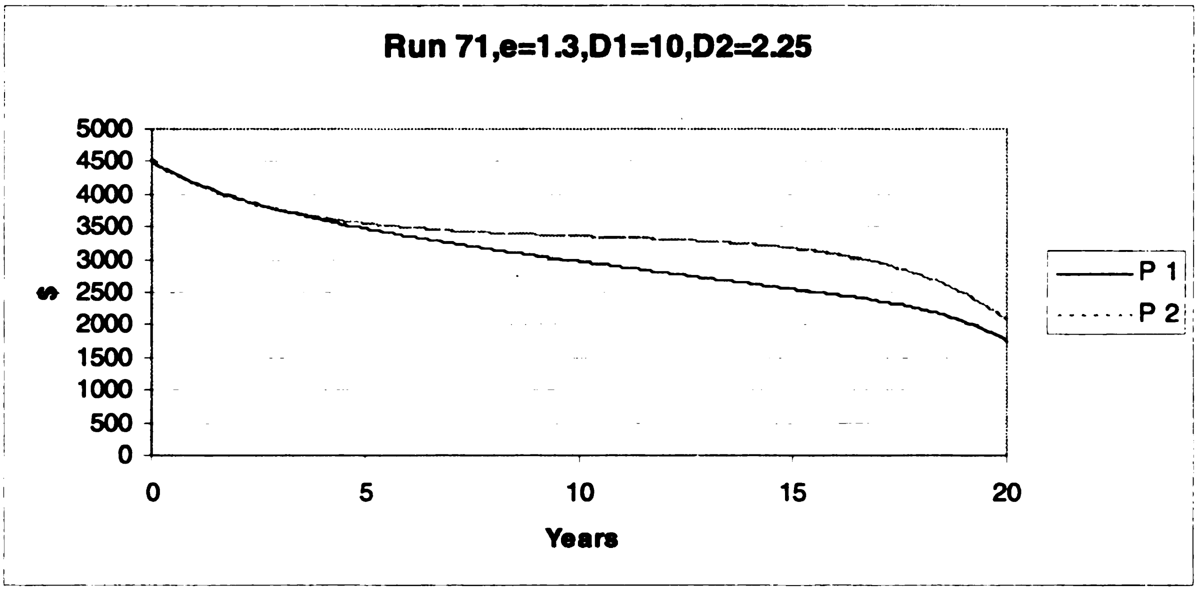


Figure 138 – Run 71 Scenario 2.8

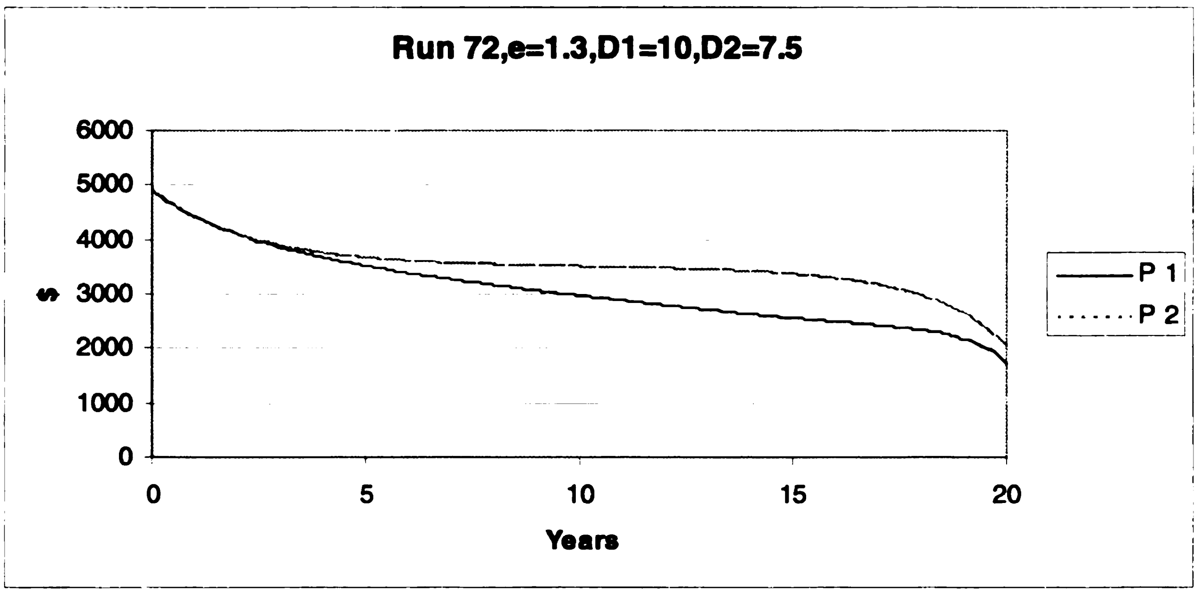


Figure 139 – Run 72 Scenario 2.8

Appendix 3

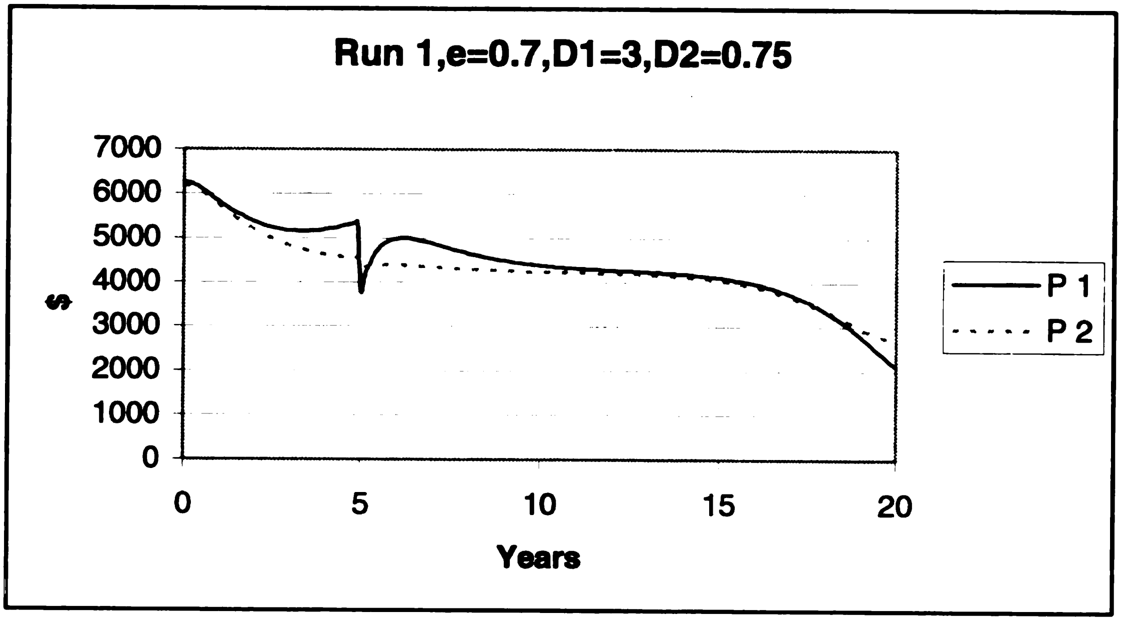


Figure 140 – Run 1 Scenario 3.0

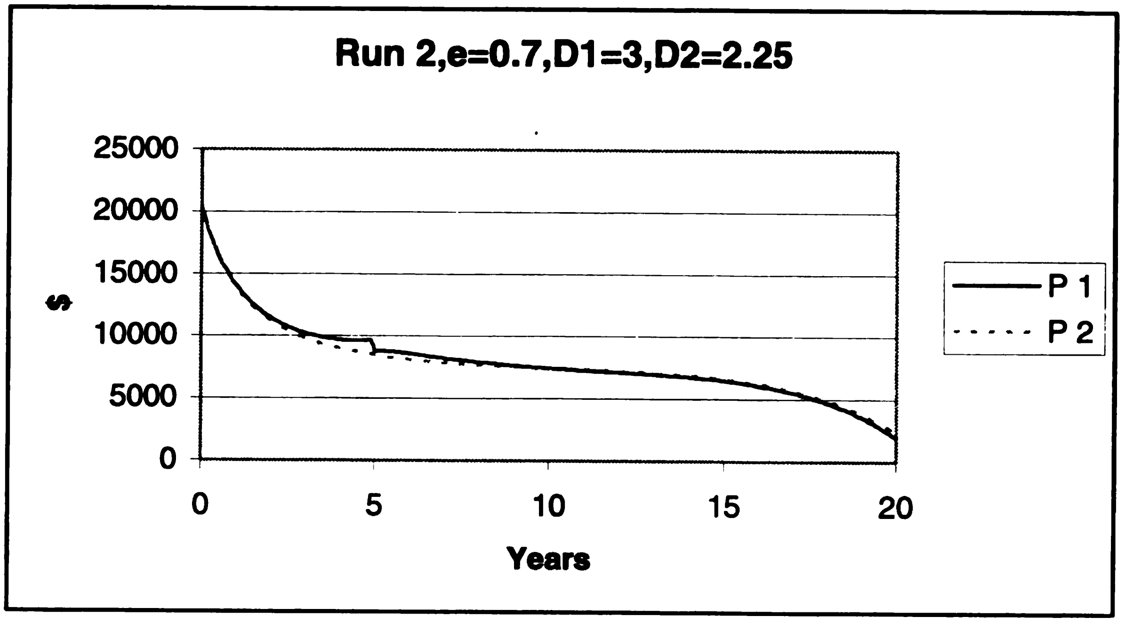


Figure 141– Run 2 Scenario 3.0

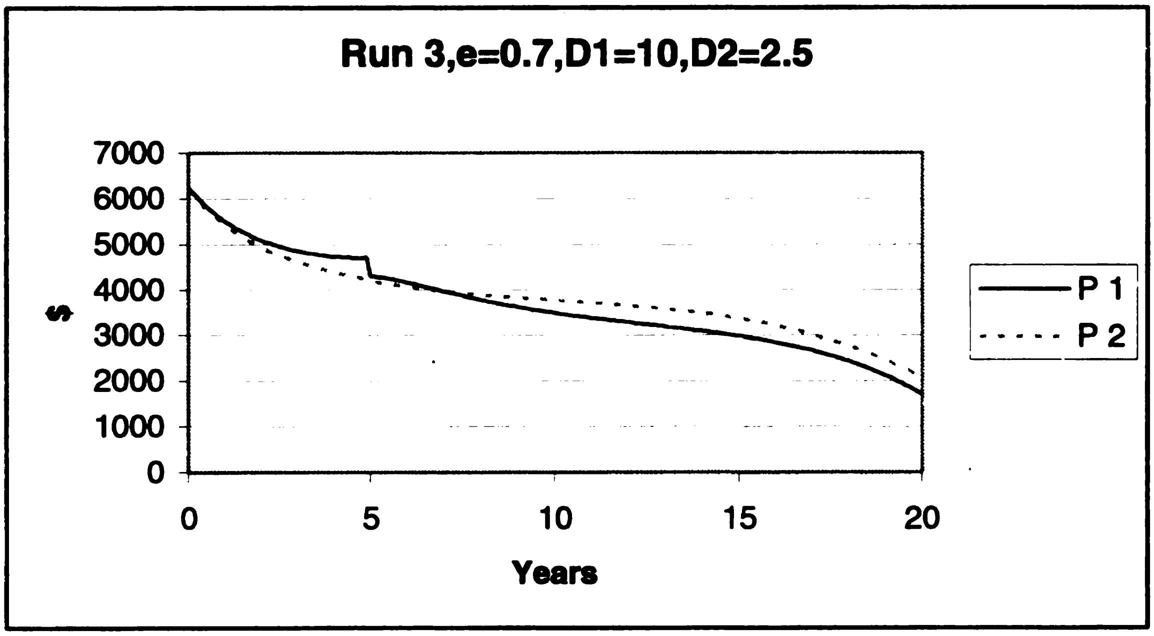


Figure 142– Run 3 Scenario 3.0

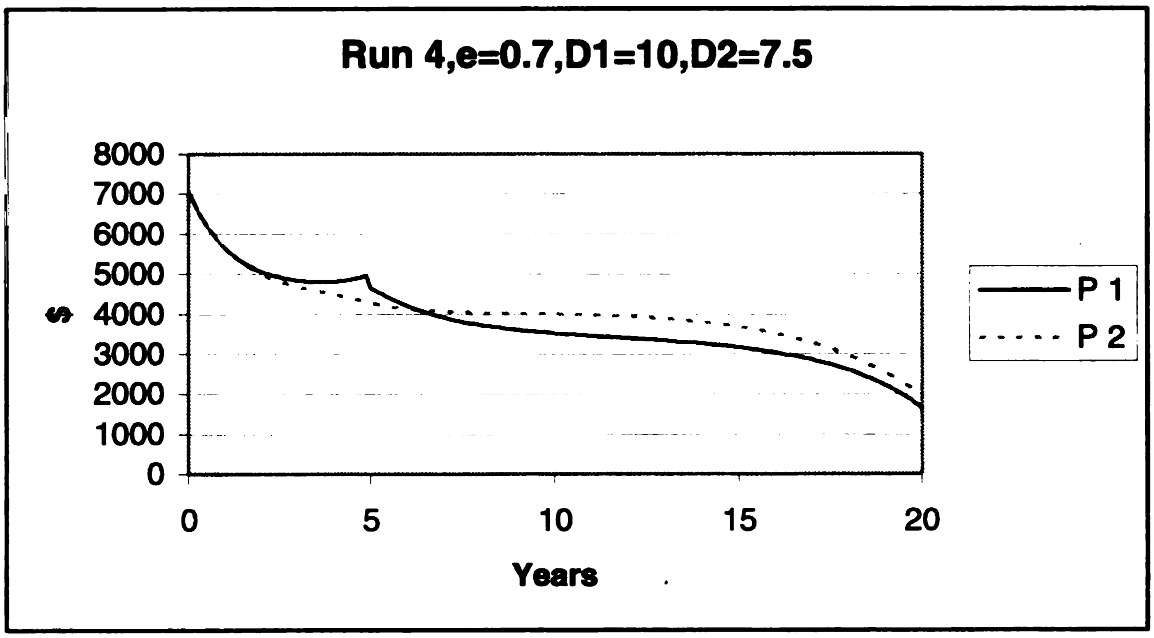


Figure 143– Run 4 Scenario 3.0

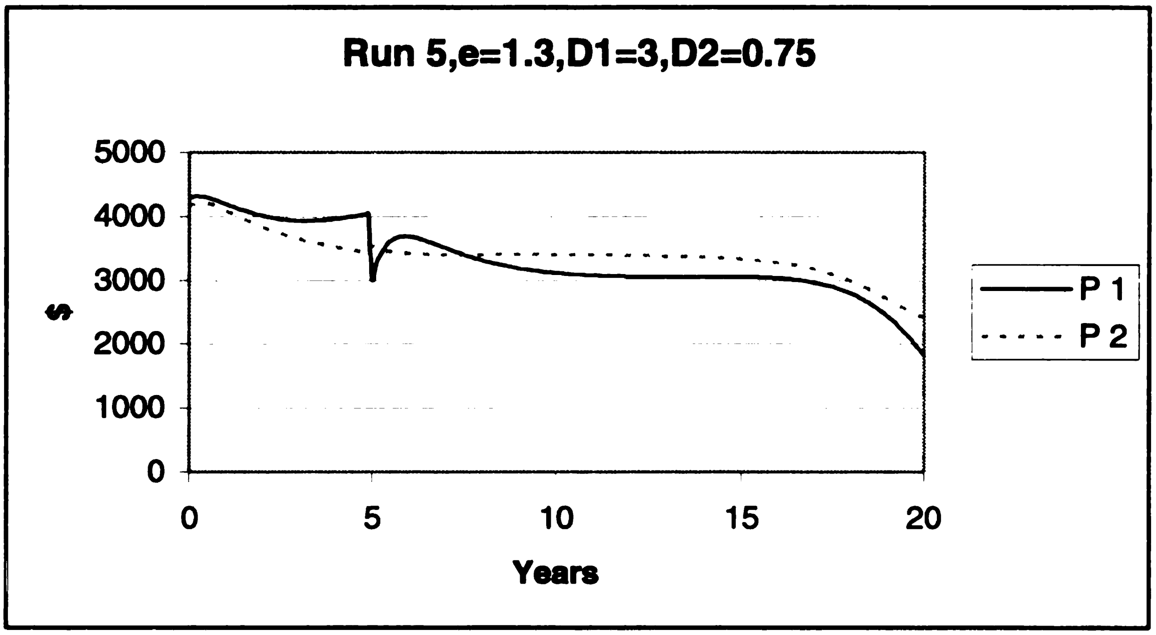


Figure 144– Run 5 Scenario 3.0

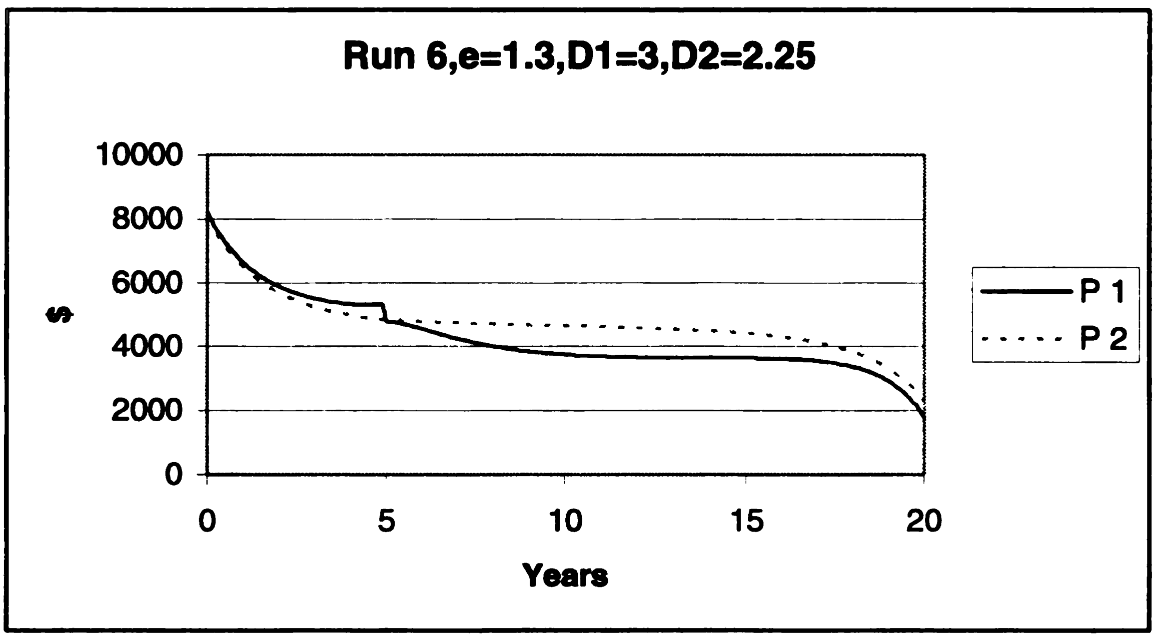


Figure 145– Run 6 Scenario 3.0

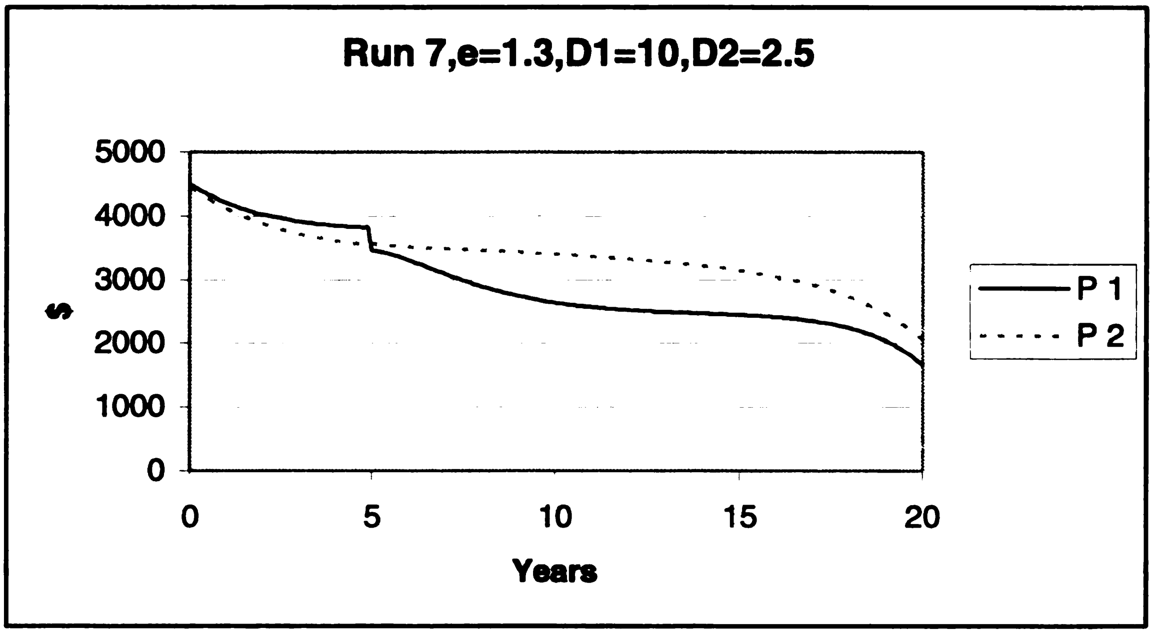


Figure 146– Run 7 Scenario 3.0

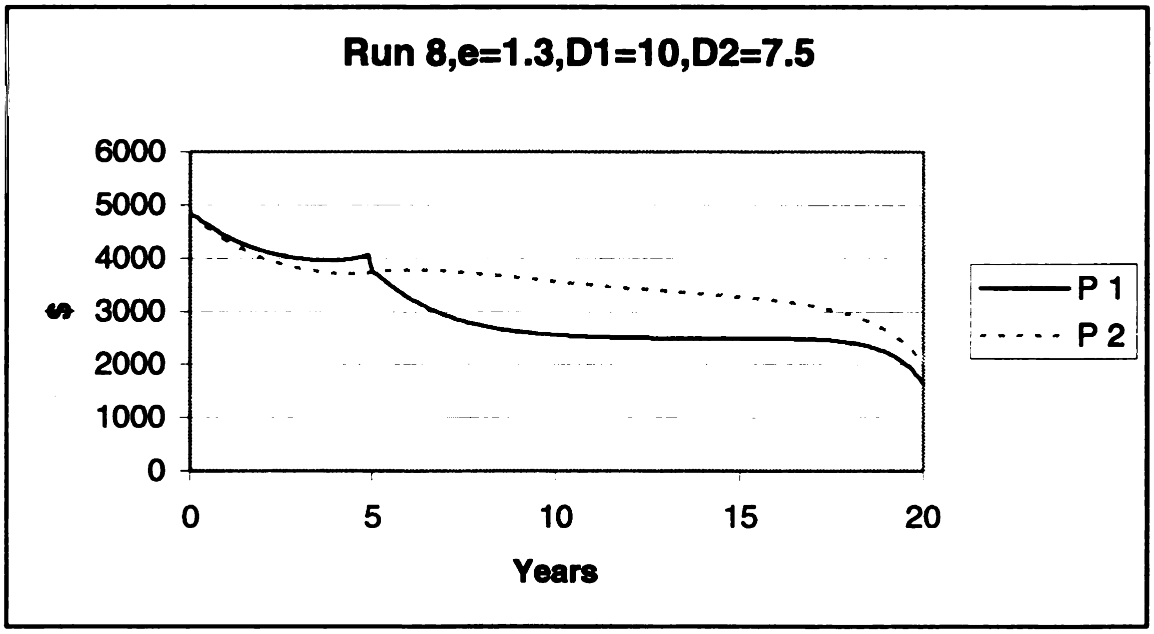


Figure 147– Run 8 Scenario 3.0

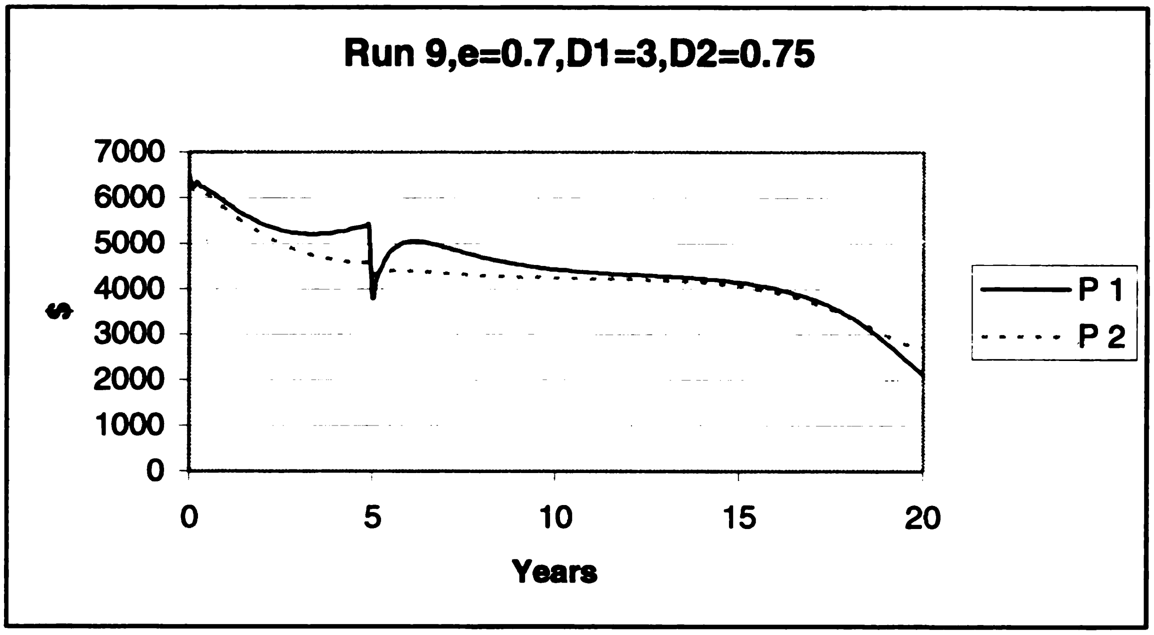


Figure 148 – Run 9 Scenario 3.1

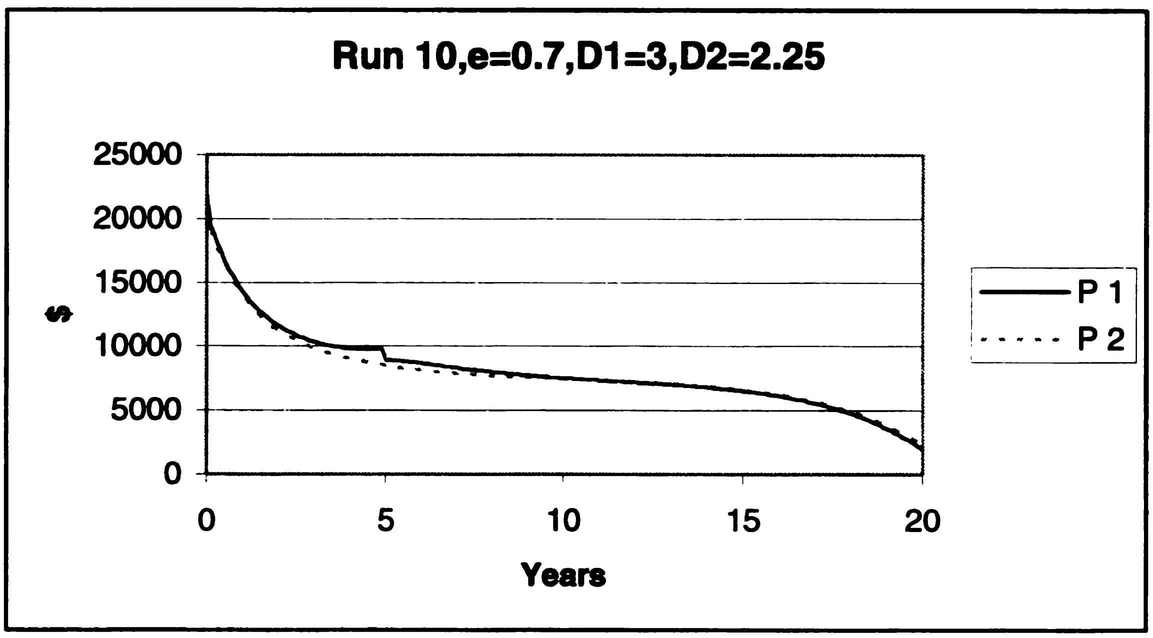


Figure 149– Run 10 Scenario 3.1

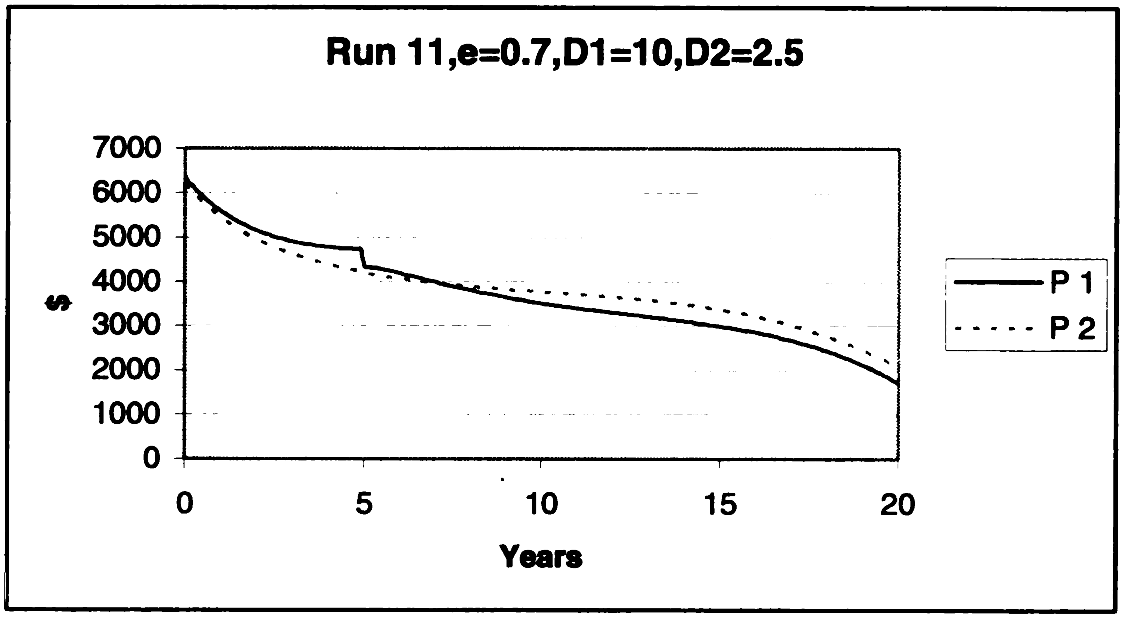


Figure 150– Run 11 Scenario 3.1

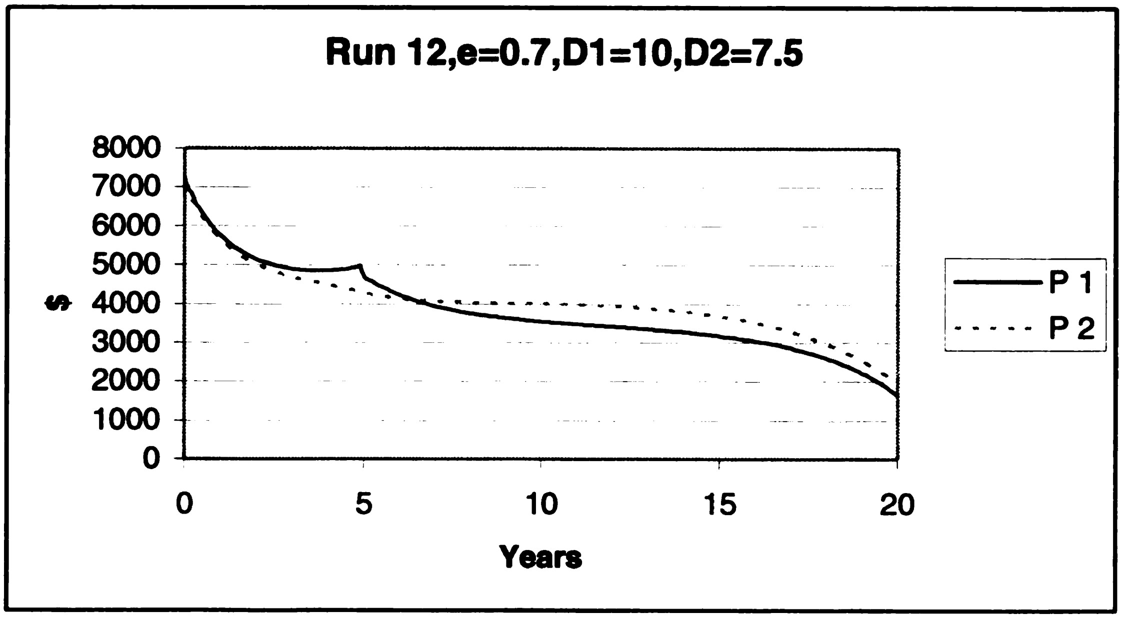


Figure 151– Run 12 Scenario 3.1

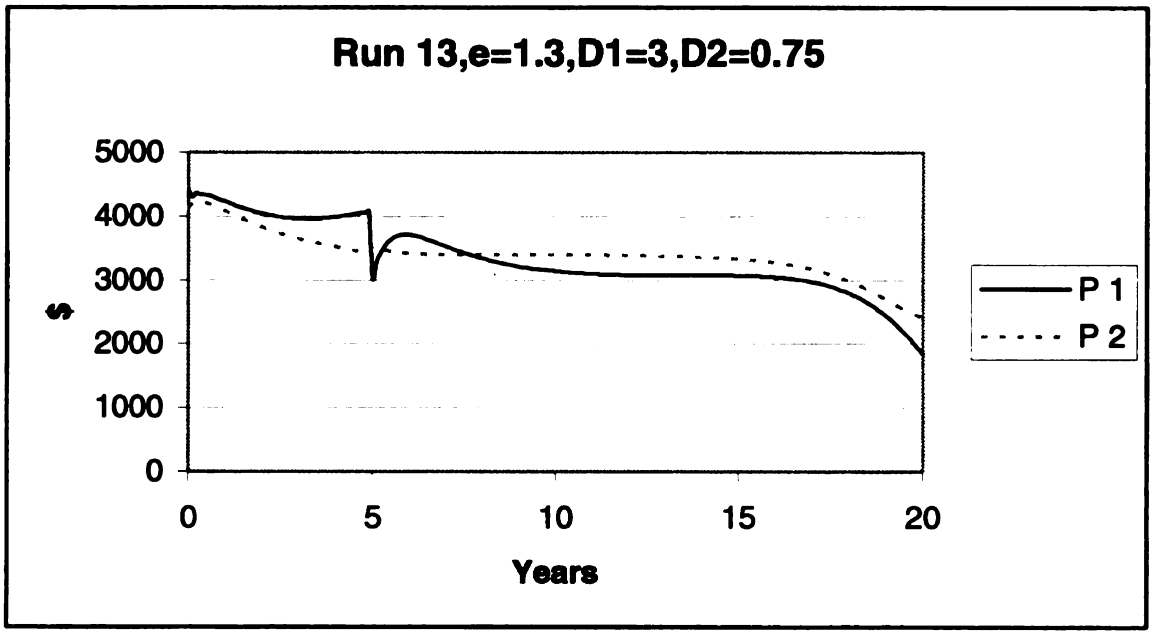


Figure 152– Run 13 Scenario 3.1

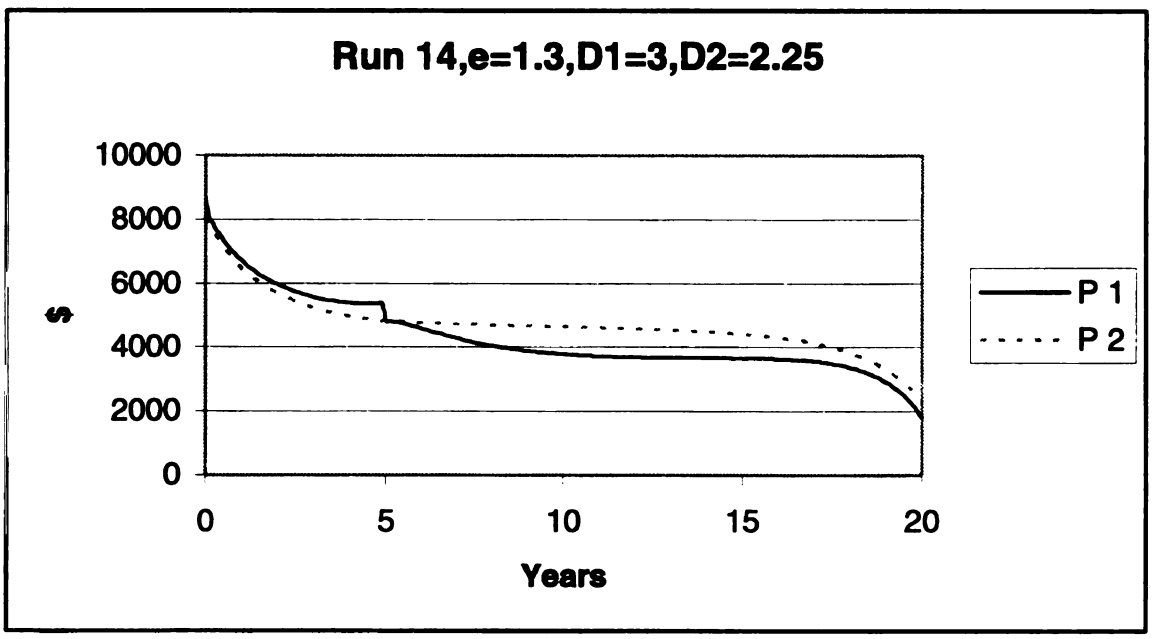


Figure 153– Run 14 Scenario 3.1

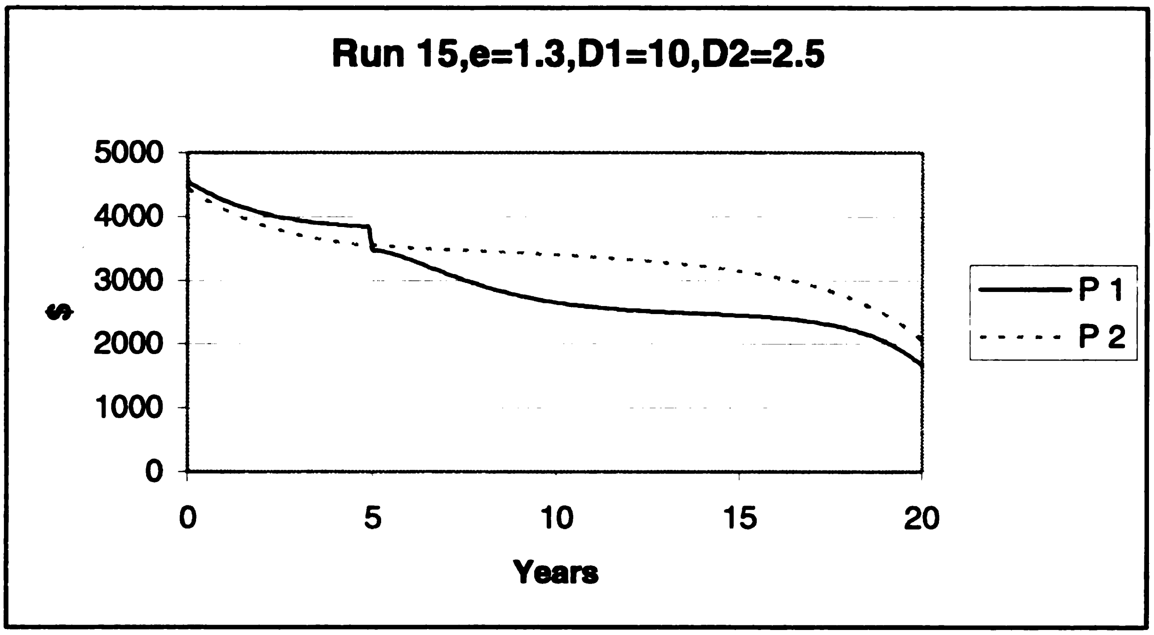


Figure 154– Run 15 Scenario 3.1

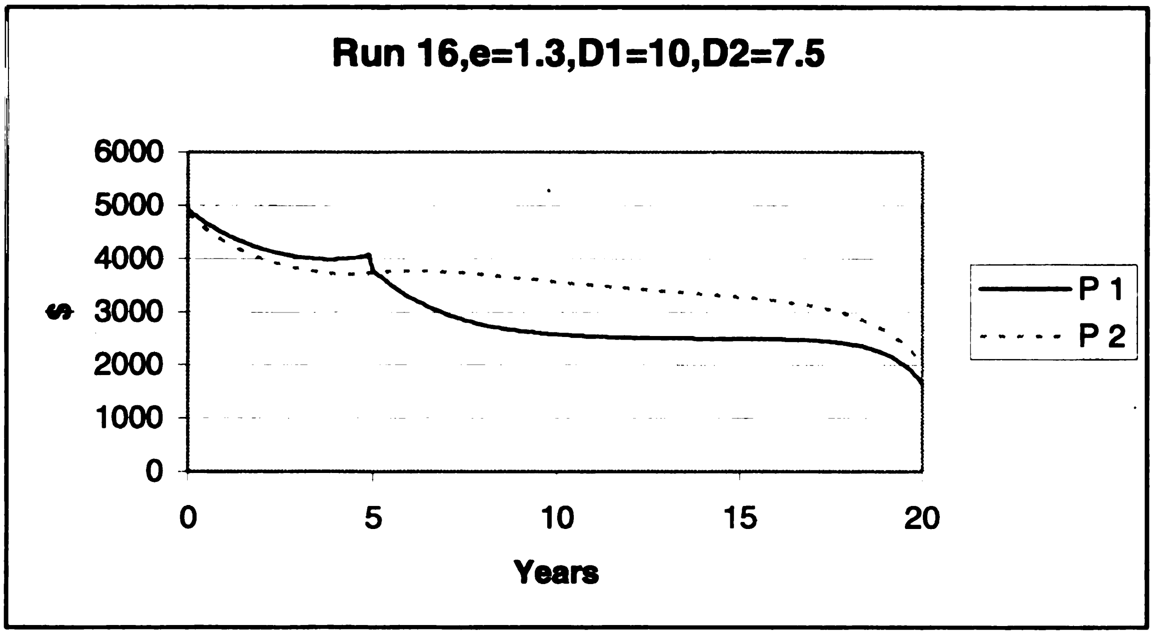


Figure 155– Run 16 Scenario 3.1

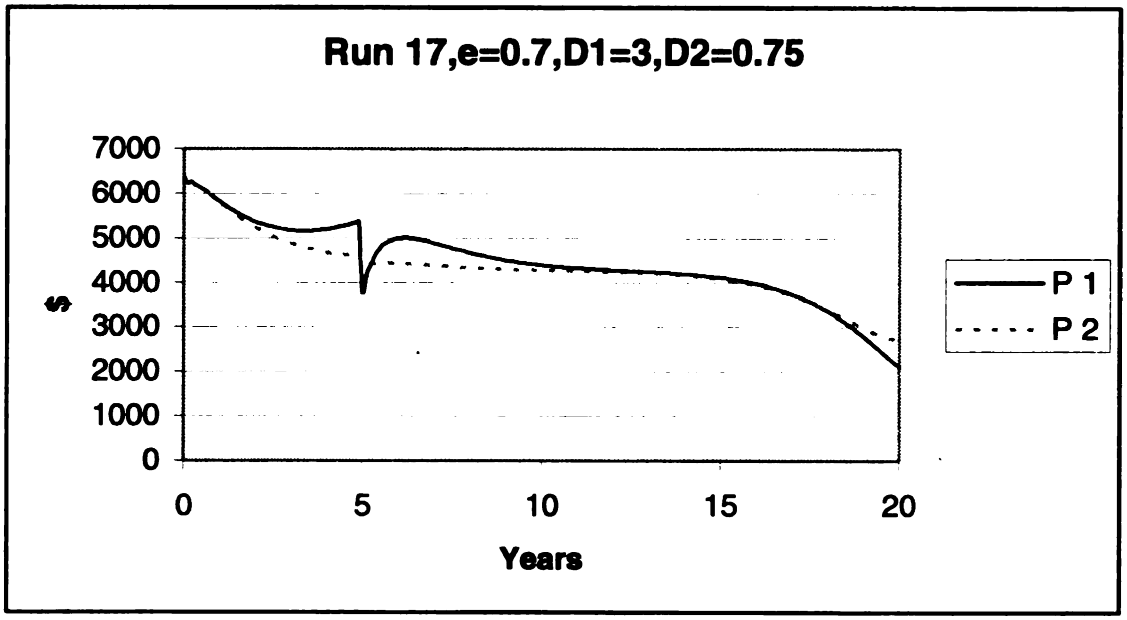


Figure 156– Run 17 Scenario 3.2

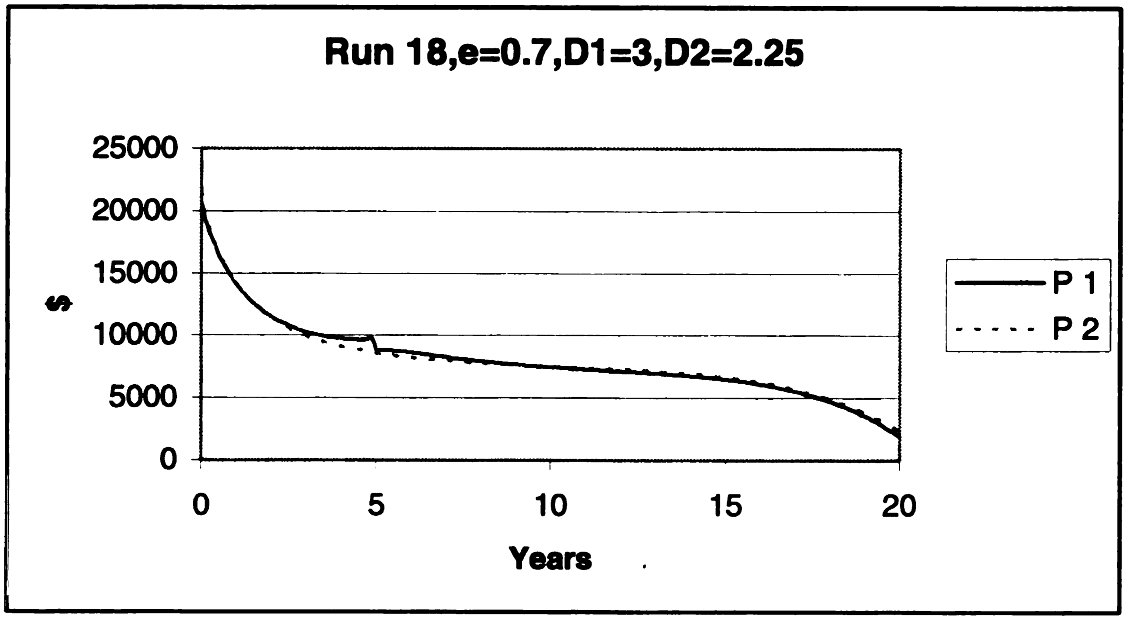


Figure 157– Run 18 Scenario 3.2

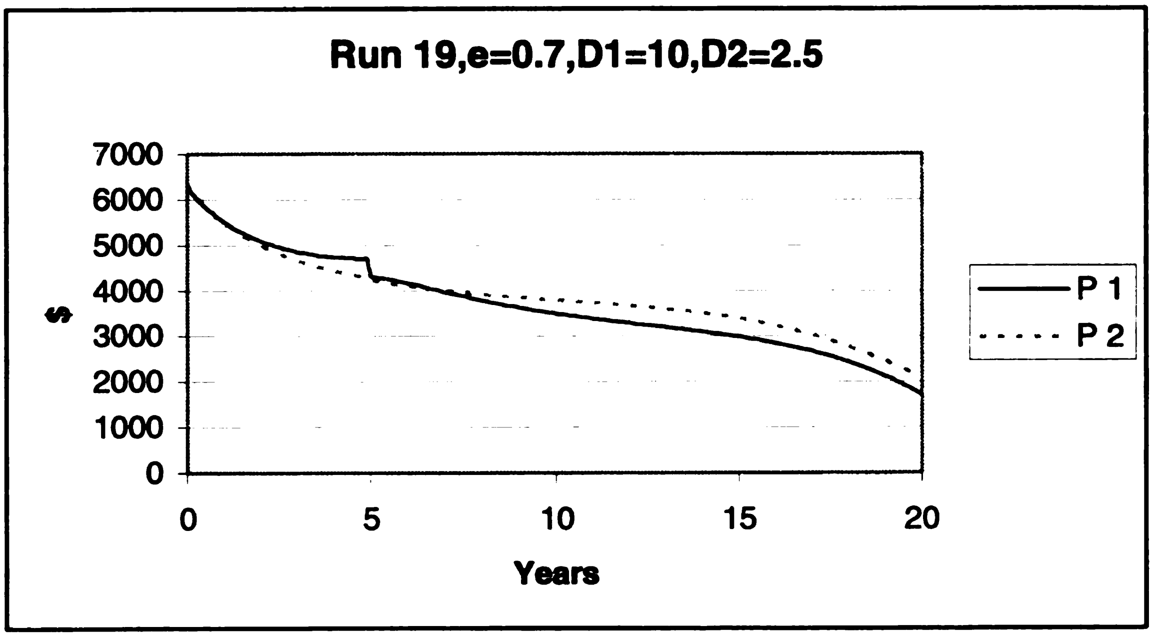


Figure 158– Run 19 Scenario 3.2

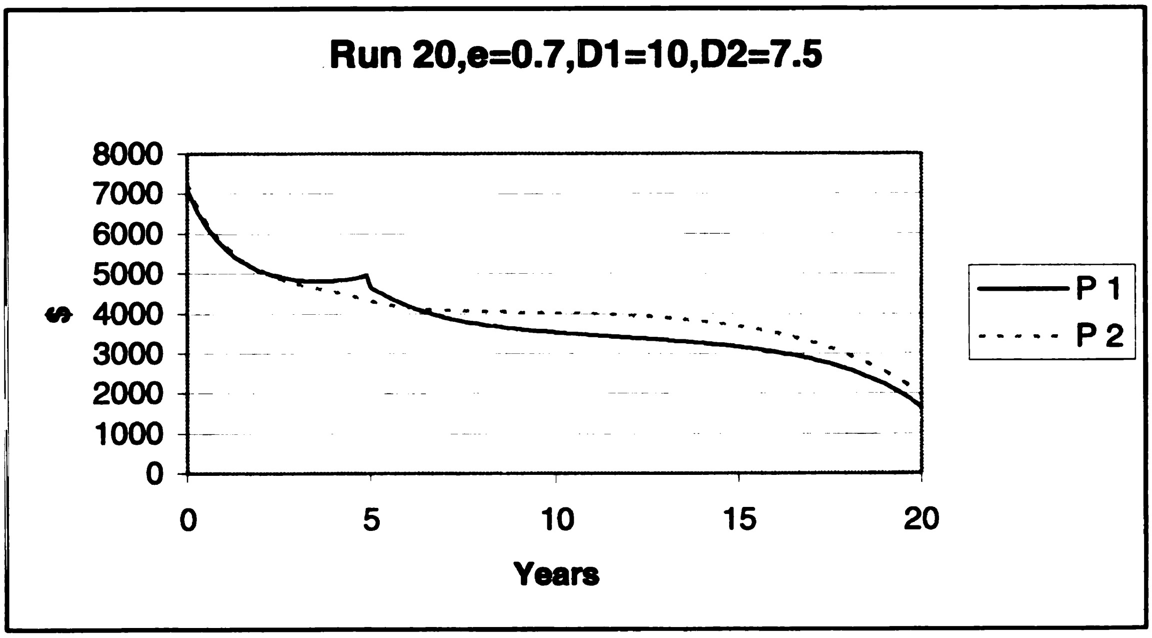


Figure 159– Run 20 Scenario 3.2

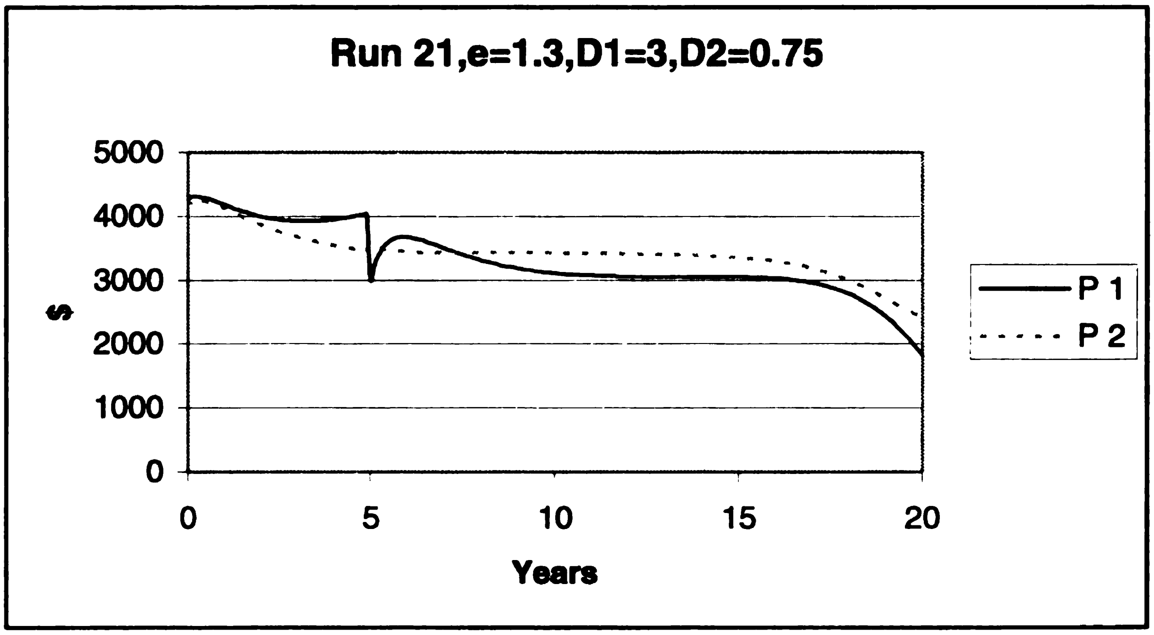


Figure 160– Run 21 Scenario 3.2

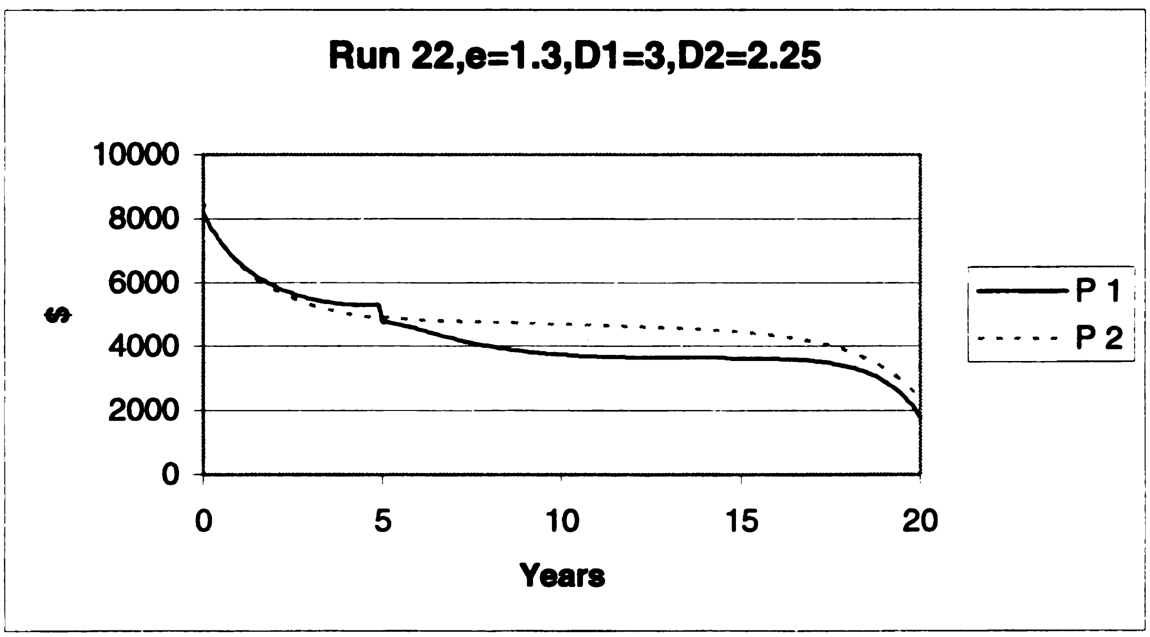


Figure 161– Run 22 Scenario 3.2

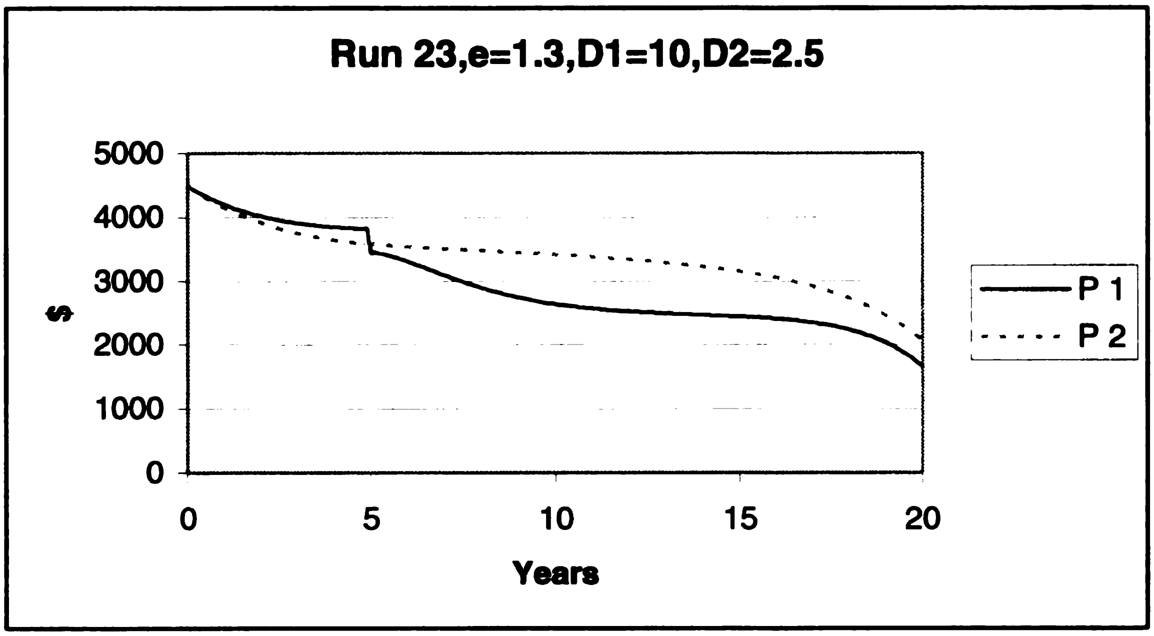


Figure 162– Run 23 Scenario 3.2

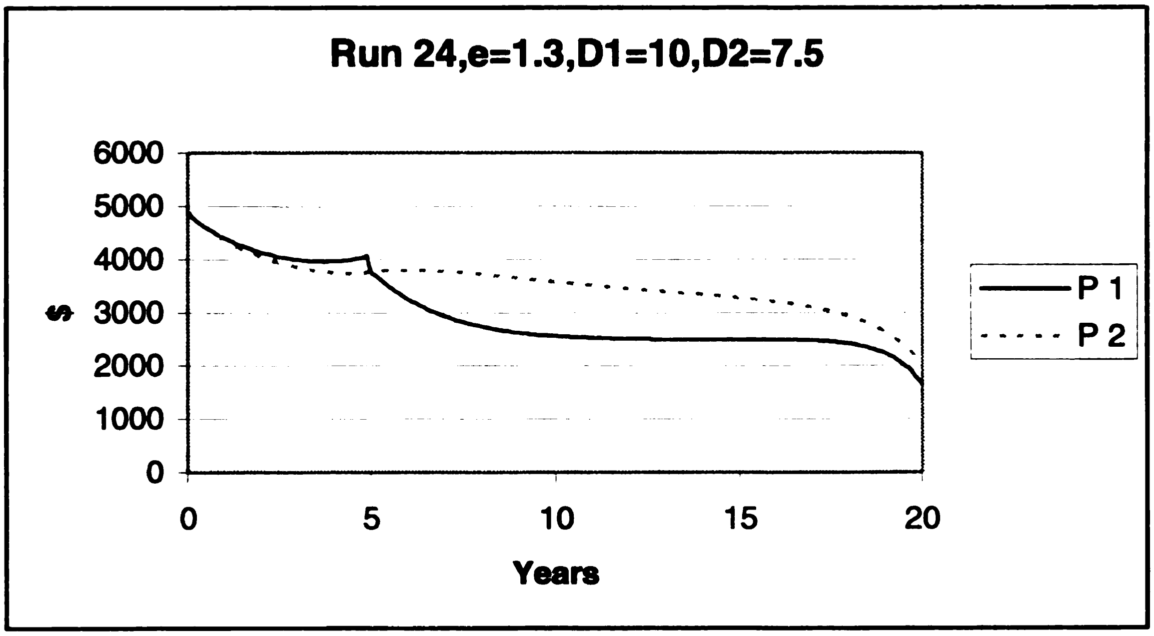


Figure 163– Run 24 Scenario 3.2

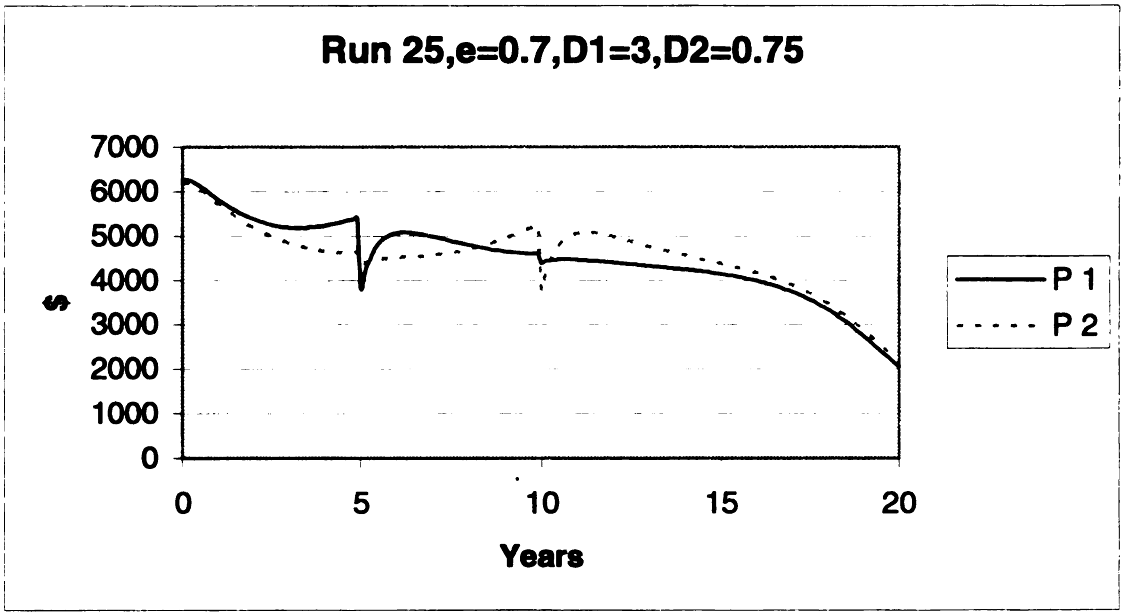


Figure 164 – Run 25 Scenario 3.3

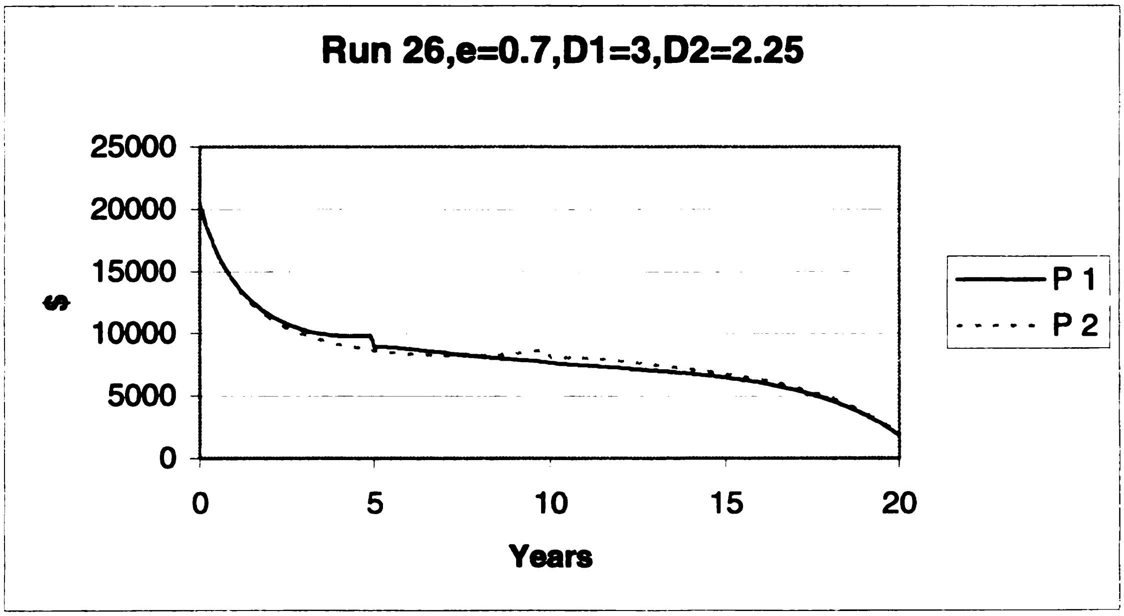


Figure 165 – Run 26 Scenario 3.3

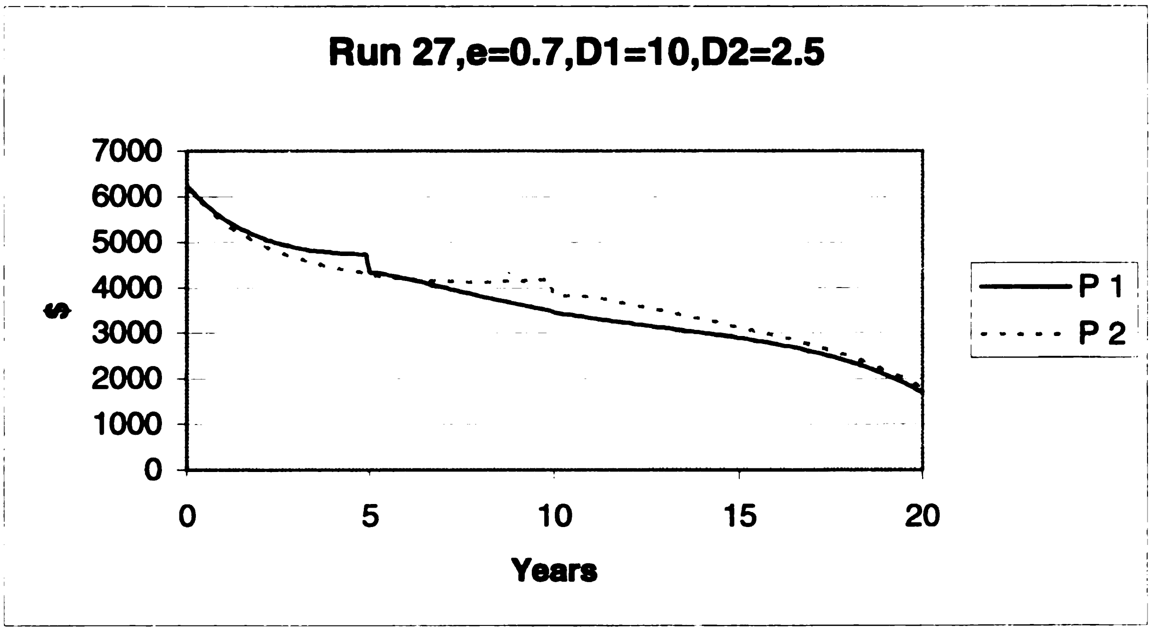


Figure 166 – Run 27 Scenario 3.3

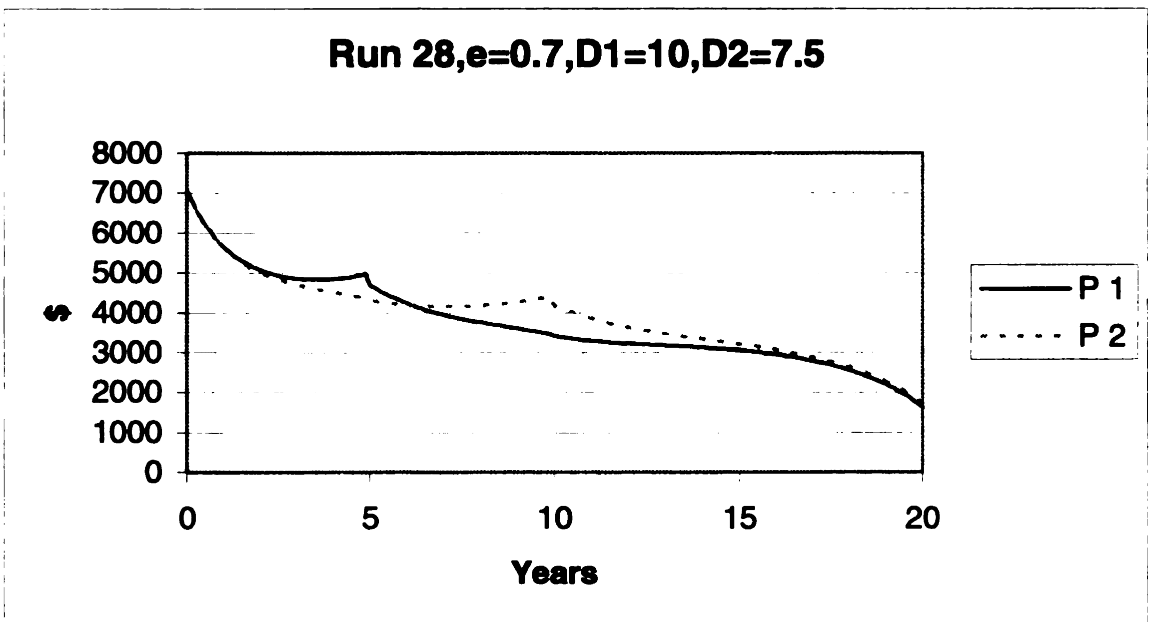


Figure 167 – Run 28 Scenario 3.3

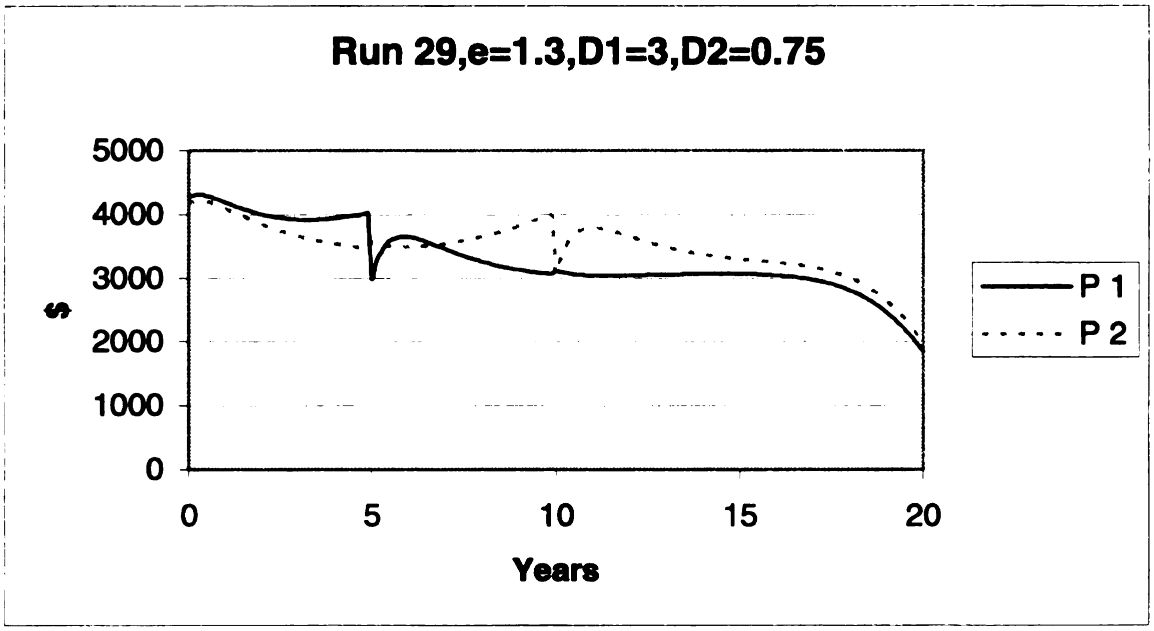


Figure 168 – Run 29 Scenario 3.3

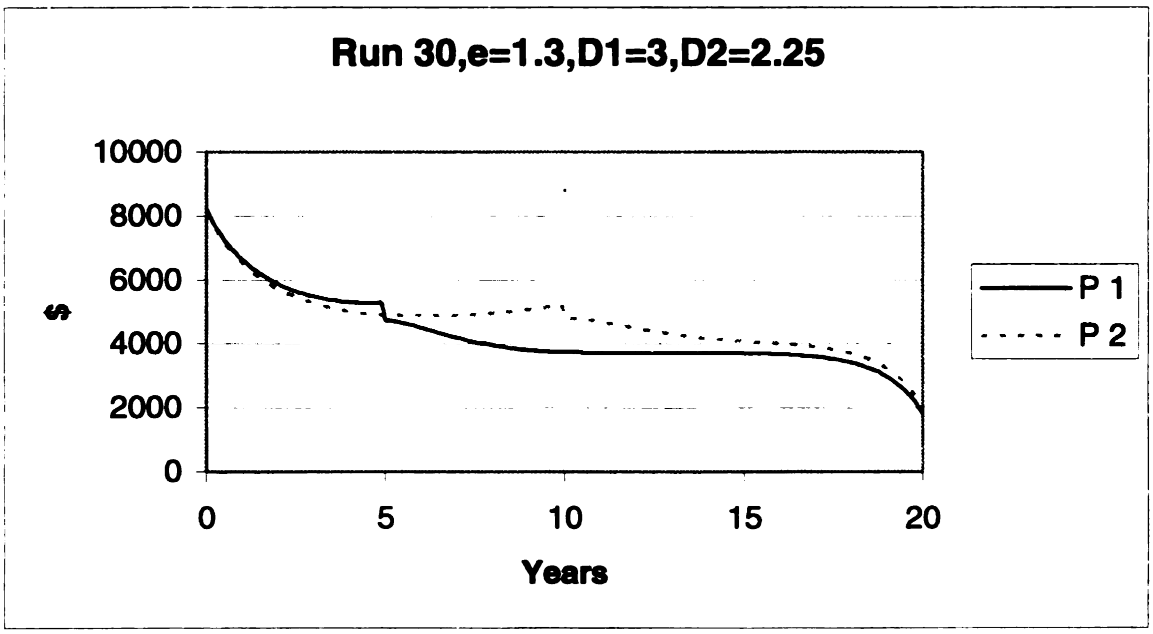


Figure 169 – Run 30 Scenario 3.3

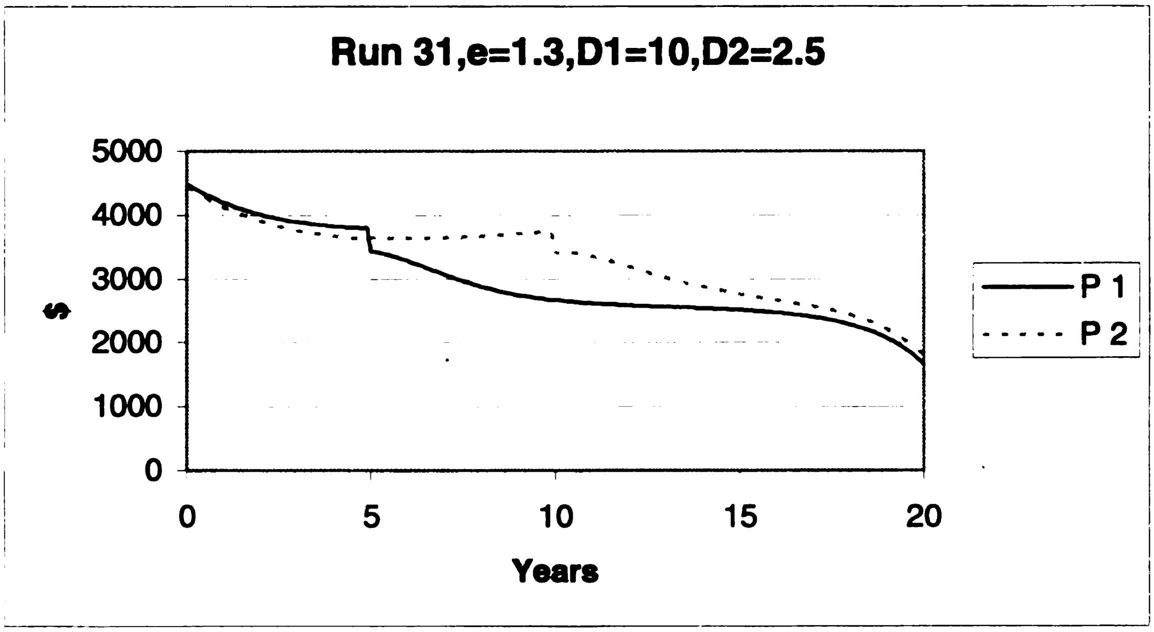


Figure 170 – Run 31 Scenario 3.3

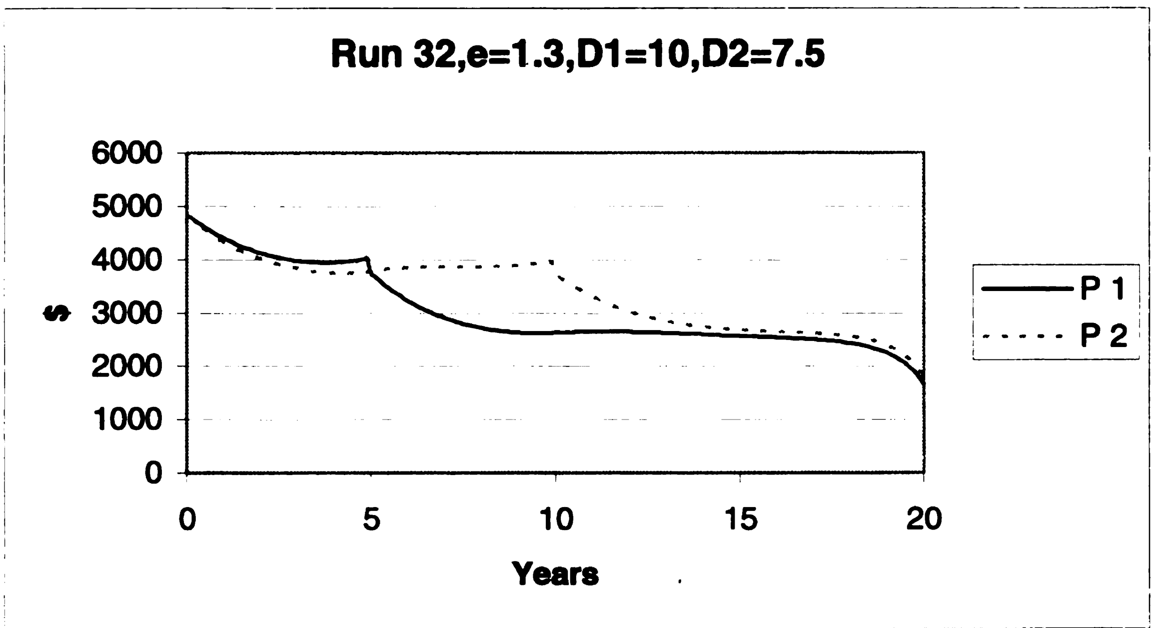


Figure 171 – Run 32 Scenario 3.3

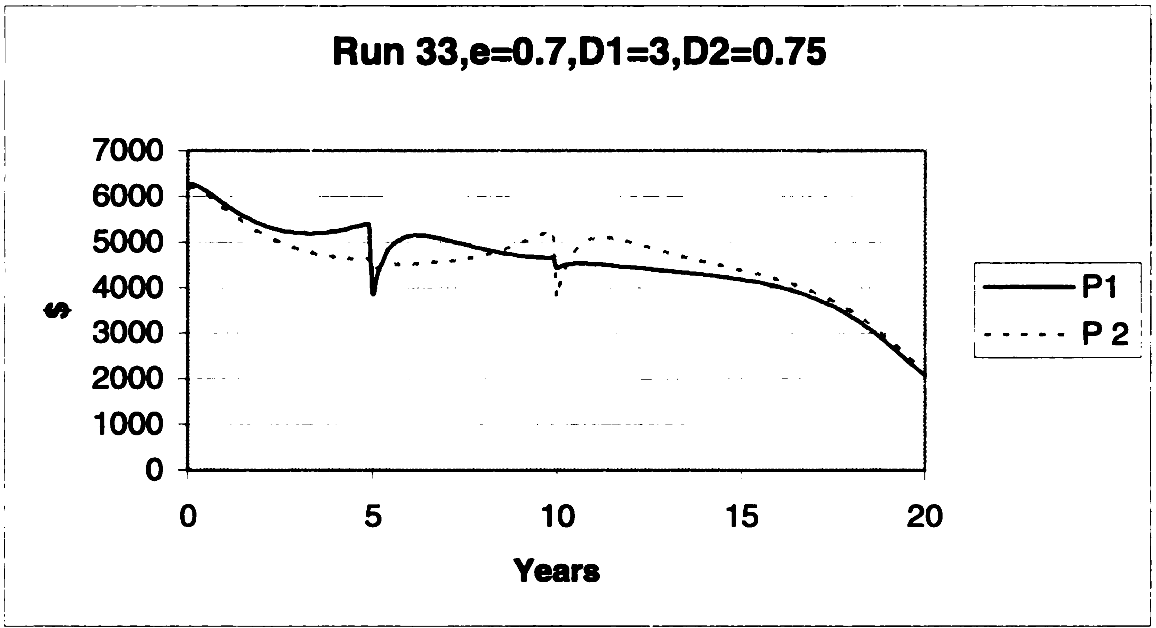


Figure 172 – Run 33 Scenario 3.4

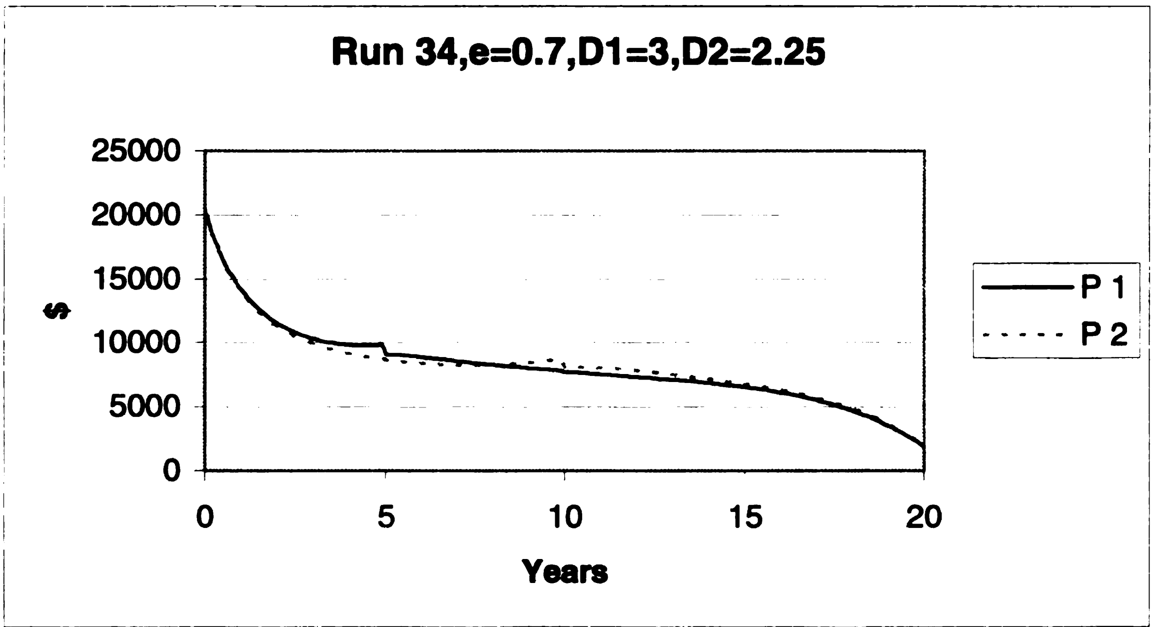


Figure 173 – Run 34 Scenario 3.4

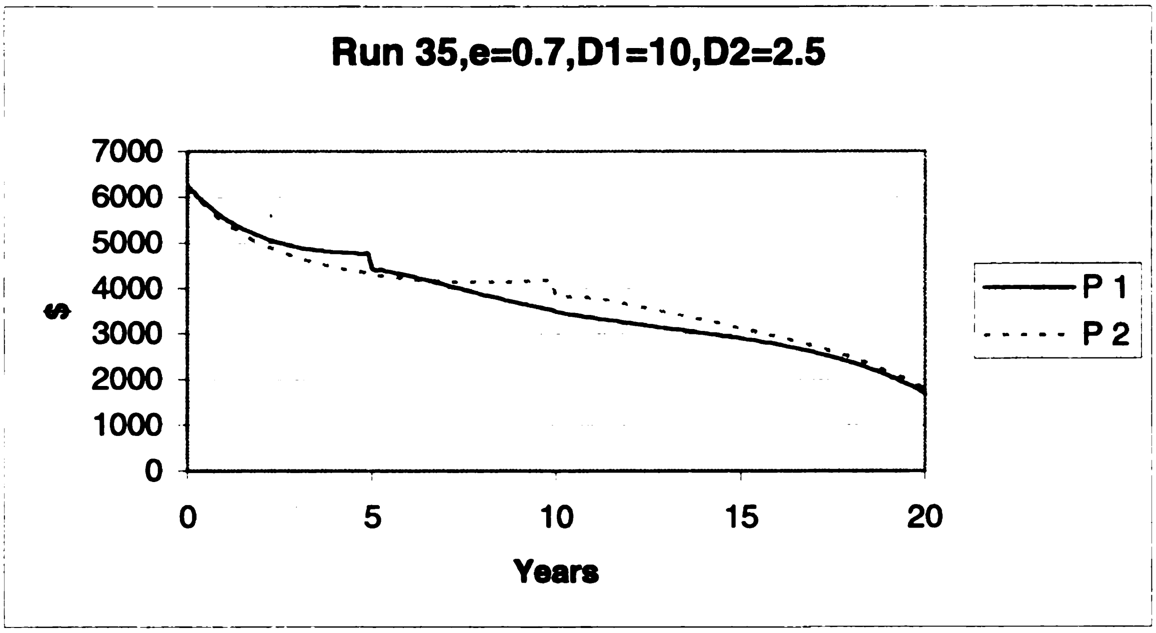


Figure 174 – Run 35 Scenario 3.4

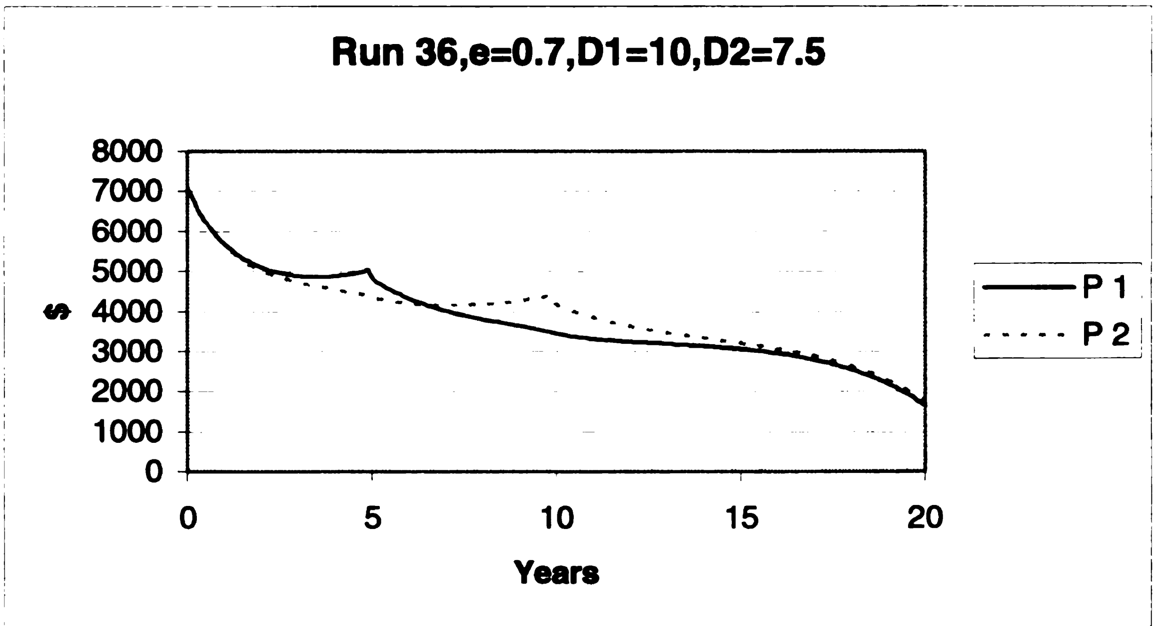


Figure 175 – Run 36 Scenario 3.4

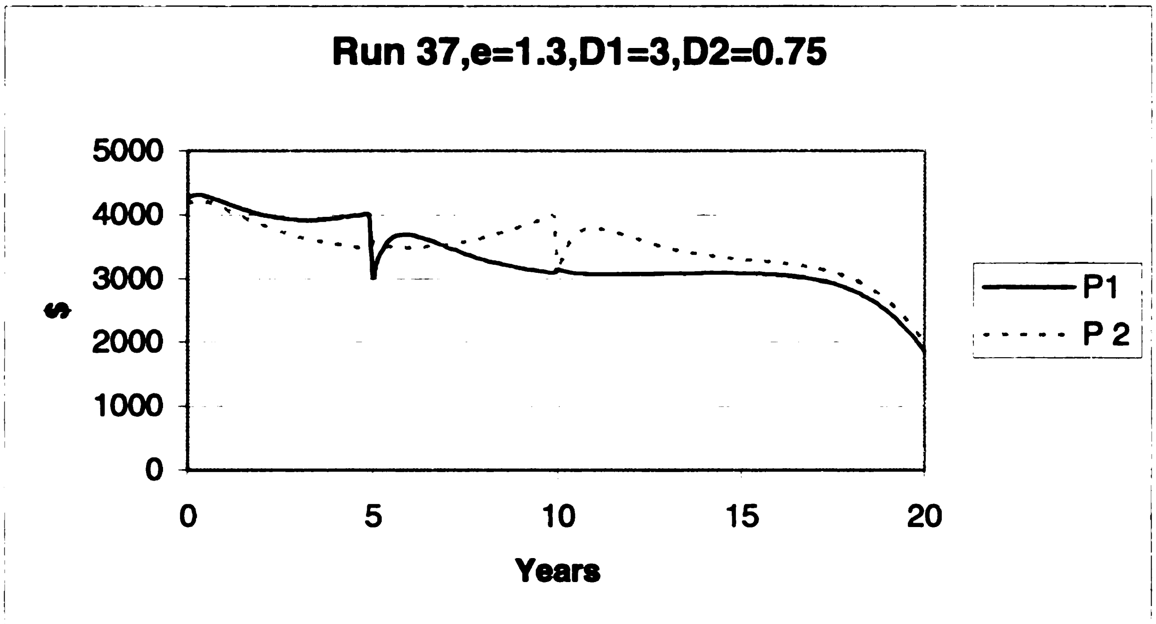


Figure 176 – Run 37 Scenario 3.4

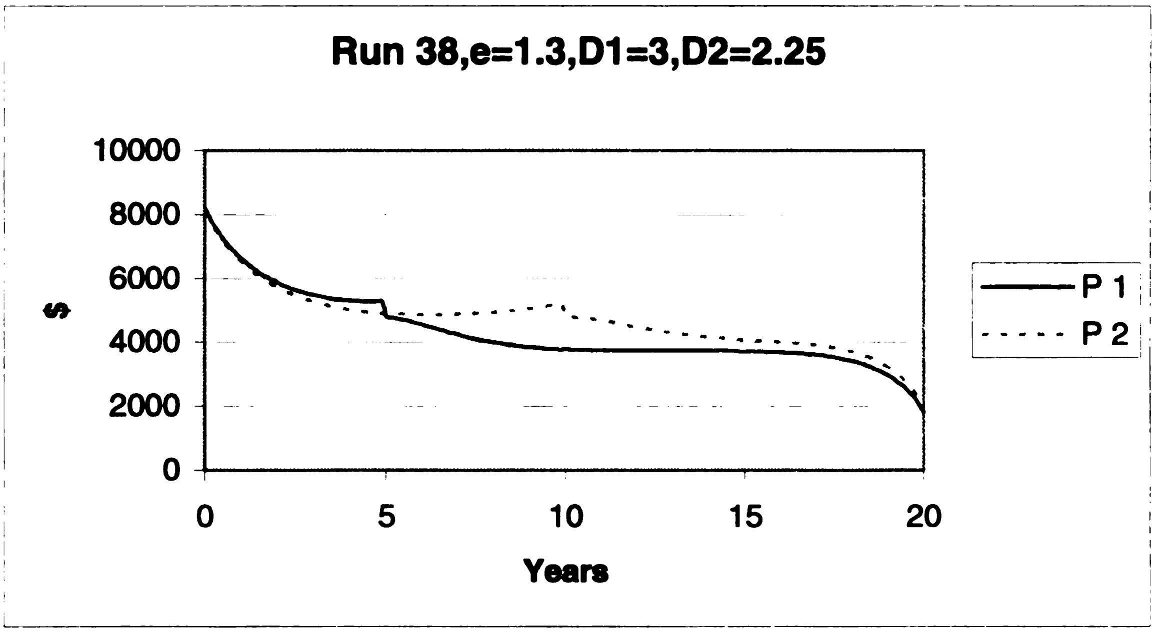


Figure 177 – Run 38 Scenario 3.4

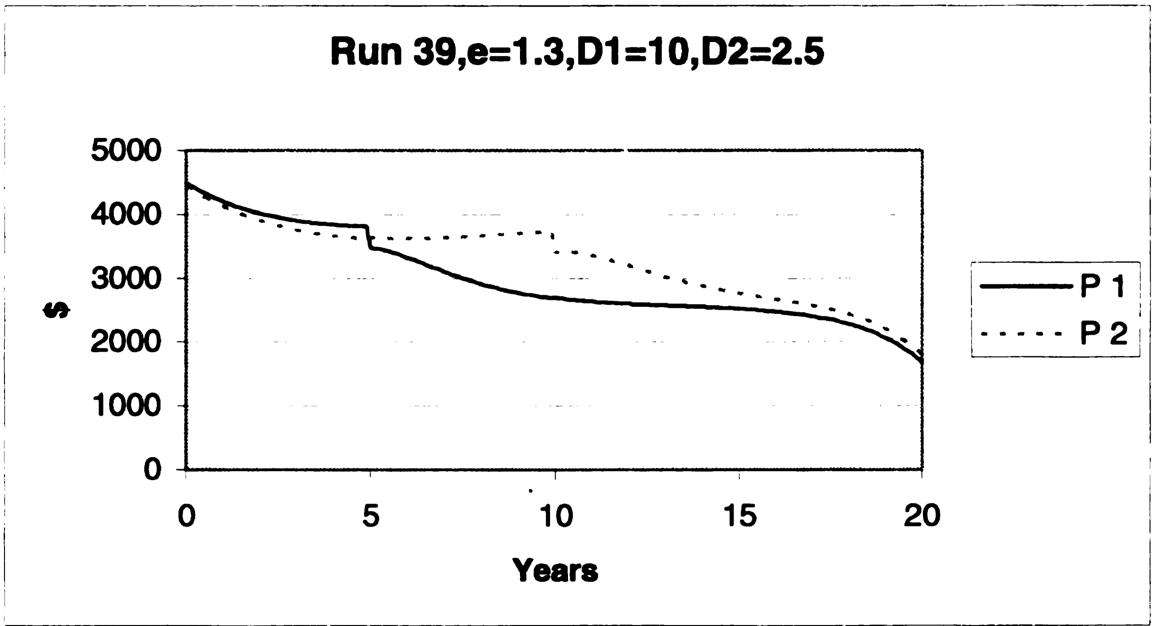


Figure 178 – Run 39 Scenario 3.4

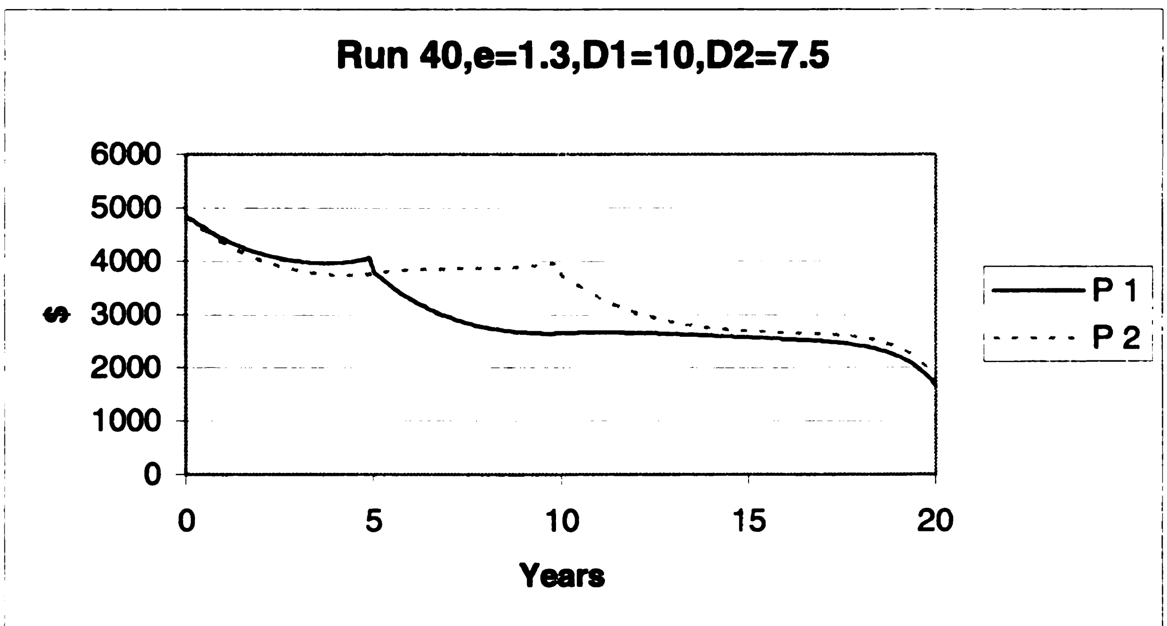


Figure 179 – Run 40 Scenario 3.4

BIBLIOGRAPHY

Advertisers, Leading National (1977-2003), Ad $ Summary. New York: Leading National Advertisers, inc.

Armstrong, Mark and John Vickers (2001), "Competitive Price Discrimination," RAND Journal of Economics, 32 (4), 579-605.

Axelrod, Robert and Michael D. Cohen (1999), Harnessing Complexity: Organizational Implications of a Scientific Frontier. New York, NY: The Free Press.

Barney, Jay (1991), "Special Theory Forum, The Resource-Based Model of the Firm: Origins, Implications and Prospects," The Journal of Management, 17, 97-98.

Barney, Jay B. (2001), "Is the Resource-Based "View a Useful Perspective for Strategic Management Research? Yes," Academy of Management Review, 26 (1), 41-56.

Bass, F. M. (1969), "A New Product Growth Model for Consumer Durables," Management Science, 15, 215-27.

Bass, Frank M. and Darral G. Clarke (1972), "Testing Distributed Lag Models of Advertising Effect," Journal of Marketing Research, 9, 298-308.

Chintagunta, Pradeep K. and Naufel J. Vilcassim (1992), "An Empirical Investigation of Advertising Strategies in a Dynamic Duopoly," Management Science, 38 (9), 1230-44.

Clarke, Darral G. (1976), "Econometric Measurement of the Duration of Advertising Effect on Sales," Journal of Marketing Research, 13, 345-57.

---- (1979), "Measuring the Cumulative Effects of Advertising on Sales: A Response to Peles," Journal of Marketing Research, 16, 286-89.

Deal, Kenneth R. (1979), "Optimizing Advertising Expenditures in a Dynamic Duopoly," Operations Research, 27 (4), 682-92.

Desai, Preyas S. (2001), "Quality Segmentation in Spatial Markets: When Does Cannibalization Affect Product Line Design," Marketing Science, 20 (3), 265-83.

Devaraj, S., K. F. Matta, and E. Conlon (2001), "Product and service quality: The antecedents of customer loyalty in the automotive industry," Production and Operations Management, 10 (4), 424-39.

Dockner, Engelbert and Steffen Jorgensen (1988), "Optimal Pricing Strategies for New Products in Dynamic Oligopolies," Marketing Science, 7 (4), 315-34.

Dockner, Engelbert, Steffen Jorgensen, Ngo Van Long, and Gerhard Sorger (2000), Differential Games in Economics and Management Science. Cambridge, UK: Cambridge University Press.

Dolan, Robert J. and Abel P. Jeuland (1981), "Experience Curves and Dynamic Demand Models: Implications for Optimal Pricing Strategies," Journal of Marketing, 45 (1), 52.

Dorfman, Robert and Peter O. Steiner (1954), "Optimal Advertising and Optimal Quality," The American Economic Review, 44 (5), 826-36.

El Ouardighi, Fouad and Charles S Tapiero (1998), "Quality and the diffusion of innovations," European Journal of Operational Research, 106 (1), 31.

Erickson, Gary M. (1991), Dynamic Models of Advertising Competition Open- and Closed-Loop Extensions. Norwell, MA: Kluwer Academic Publishers.

---- (1985), "A Model of Advertising Competition," Journal of Marketing Research, 22, 297-304.

---- (1997), "Note. Dynamic Conjectural Variations in a Lanchester Oligopoly," Management Science, 43 (11), 1603-08.

Feichtinger, G., R. F. Hartl, and S. P. Sethi (1994), "Dynamic Optimal-Control Models in Advertising - Recent Developments," Management Science, 40 (2), 195-226.

Feinberg, Fred M. (1992), "Pulsing Policies for Aggregate Advertising Models," Marketing Science, 11 (3), 221-34.

Fine, Charles H. (1986), "Quality Improvement and Learning in Productive Systems," Management Science, 32 (10), 1301-15.

Foster, S. T. and E. E. Adam (1996), "Examining the impact of speed of quality improvement on quality-related costs," Decision Sciences, 27 (4), 623-46.

Fruchter, G. E. (1999), "Oligopoly advertising strategies with market expansion," Optimal Control Applications & Methods, 20 (4), 199-211.

Fruchter, G. E. and S. Kalish (1998), "Dynamic promotional budgeting and media allocation," European Journal of Operational Research, 111 (1), 15-27.

Fruchter, Gila E. and Sholomo Kalish (1997), "Closed-Loop Advertising Strategies in a Duopoly," Management Science, 43 (1), 54-63.

Fudenberg, Drew and Jean Tirole (1996), Game Theory. Cambridge, MA: The MIT Press.

Garvin, David A. (1988), Managing Quality: The Strategic and Competitive Edge. New York: The Free Press.

---- (1983), "Quality on the Line," Harvard Business Review, 64-75.

Gerstner, Eitan (1985), "Do Higher Prices Signal Higher Quality?," Journal of Marketing Research, 22, 215-27.

Godfrey, P.C. and C.W.L. Hill (1995), "The Problem of Unobservables in Strategic Management Research," Strategic Management Journal, 16, 519-33.

Horsky, Dan (1990), "A Diffusion Model Incorporating Product Benefits, Price, Income and Information," Marketing Science, 9 (4), 342-65.

---- (1977), "An Empirical Analysis of the Optimal Advertising Policy," Management Science, 23 (10), 1037-49.

Horsky, Dan and Karl Mate (1988), "Dynamic Advertising Strategies of Competing Durable Good Producers," Marketing Science, 7 (4, Special Issue on Competitive Marketing Strategy), 356-67.

Horsky, Dan and Leonard S. Simon (1983), "Advertising and the Diffusion of New Products," Marketing Science, 2 (1), 1-17.

Irandoust, Manuchehr (1998), "Pricing Policy in the Swedish Automobile Market," Journal of Economics and Business, 50, 309-17.

Jacobson, Robert and David A. Aaker (1987), "The Strategic Role of Product Quality," Journal of Marketing, 51 (4), 31.

Jones, Phillip C. (1983), "Analysis of a Dynamic Duopoly Model of Advertising," Mathematics of Operations Research, 8 (1), 122-34.

Juran, J.M. and Frank M. Gryana Jr. (1980), Quality Planning and Analysis: From Product Development through Use 2nd Ed. New York, New York: McGraw-Hill Book Company.

Kalish, Shlomo (1985), "A New Product Adoption Model with Price, Advertising, and Uncertainty," Management Science, 31 (12), 1569.

Kouvelis, Panagiotis and Samar K Mukhopadhyay (1995), "Competing on design quality: A strategic planning approach for product quality with the use of a control theoretic model," Journal of Operations Management, 12 (3,4), 369.

Krishnan, Trichy V., Frank M. Bass, and Dipak C. Jain (1999), "Optimal Pricing Strategy for New Products," Management Science, 45 (12), 1650-63.

Leavitt, Harold J. (1954), "A Note on Some Experimental Findings About the Meaning of Price," Journal of Business, 27 (July), 205-10.

Lichtenstein, Donald R. and Scot Burton (1989), "The Relationship Between Perceived And Objective Price-Qual," JMR, Journal of Marketing Research, 26 (4), 429.

Lilien, Gary L., Philip Kotler, and K. Sridhar Moorthy (1992), Marketing Models. Englewood Cliffs, New Jersey: Prentice Hall.

Little, John D. C. (1979), "Aggregate Advertising Models: The State of the Art," Operations Research, 27 (4), 629-67.

Luptacik and Mikulas (1982), "Optimal Price and Advertising Policy Under Atomistic Competition," Journal of Economic Dynamics & Control, 4 (1), 57.

Mahajan, Vijay and Eitan Muller (1986), "Reflection on Advertising Pulsing Policies for Generating Awareness for New Products," Marketing Science, 5 (2), 86-106.

Mahajan, Vijay, Eitan Muller, and Frank M. Bass (1990), "New Product Diffusion Models in Marketing: A Review and Direction for Research," Journal of Marketing, 54, 1-26.

Mahajan, Vijay, Eitan Muller, and Roger A. Kerin (1984), "Introduction Strategy for New Products with Positive and Negative Word-of-Mouth," Management Science, 30 (12), 1389.

Mendez, D., K. E. Warner, and P. N. Courant (1998), "Has smoking cessation ceased? Expected trends in the prevalence of smoking in the United States," American Journal of Epidemiology, 148 (3), 249-58.

Mesak, H. I. and W. D. Berg (1995), "Incorporating price and replacement purchases in new product diffusion models for consumer durables," Decision Sciences, 26 (4), 425-49.

Mesak, H. I. and J. W. Clark (1998), "Monopolist optimum pricing and advertising policies for diffusion models of new product innovations," Optimal Control Applications & Methods, 19 (2), 111-36.

Mesak, H.I. and H. Zhang (2001), "Optimal Advertising Pulsation Policies: A Dynamic Programming Approach," Journal of the Operational Research Society, 52 (11), 1244-55.

Milgrom, Paul and John Roberts (1987), "Informational Asymmetries, Strategic Behavior, and Industrial Organization," The American Economic Review, 77 (2, Papers and Proceedings of the Ninety-Ninth Annual Meeting of the American Economic Association), 184-93.

---- (1986a), "Price and Advertising Signals of Product Quality," The Journal of Political Economy, 94 (4), 796-821.

---- (1990), "Rationalizability, Learning, and Equilibrium in Games with Strategic Complementarities," Econometrica: Journal of the Econometric Society, 58 (6), 1255-77.

---- (1986b), "Relying on the Information of Interested Parties," The Rand Journal of Economics, 17 (1), 18-32.

Montgomery, D. C. (1985), Introduction to statistical Quality Control. New York: Wiley.

Muller, Eitan (1983), "Trial/Awareness Advertising Decisions: A Control Problem with Phase Diagrams with Non-Stationary Boundaries," Journal of Economic Dynamics & Control, 6 (4), 333.

Naik, Prasad A., Murali K. Mantrala, and Alan G. Sawyer (1998), "Planning Media Schedules in the Presence of Dynamic Advertising Quality," Marketing Sciences, 17 (3), 214-35.

Narasimhan, R. and D. Mendez (2001), "Strategic aspects of quality: A theoretical analysis," Production and Operations Management, 10 (4), 514-26.

Narasimhan, Ram, Soumen Ghosh, and David Mendez (1993), "A Dynamic Model of Product Quality and Pricing Decisions on Sales Response," Decision Sciences, 24 (5), 893-908.

Narasimhan, Ram, David Mendez, and Soumen Ghosh (1996), "An Examination of the Effect of Continuous Quality Improvements on Optimal Pricing for Durable Goods," Decision Sciences, 27 (3), 389-413.

Nelson, Phillip (1974), "Advertising as Information," The Journal of Political Economy, 82 (4), 729-54.

---- (1970), "Information and Consumer Behavior," The Journal of Political Economy, 78 (2), 311-29.

Ouchi, William G. (1982), Theory Z: How American Business Can Meet the Japanese Challenge. New York: Avon.

Peles, Yoram C. (1979), "Econometric Measurement of the Duration of Advertising Effect on Sales: A Comment," Journal of Marketing Research, 16, 284-85.

Phillips, Lynn W., Dae R. Chang, and Robert D. Buzzell (1983), "Product Quality, Cost Position and Business Performance: A Test of Some Key Hypotheses," Journal of Marketing, 47 (2), 26-44.

Priem, Richard L. and John E. butler (2001), "Tautology in the Resource-Based View and the Implication of Externally Determined Resource Value: Further Comments," Academy of Management Review, 28 (1), 57-66.

Rao, Akshay R. and Kent B. Monroe (1989), "The Effect of Price, Brand Name and Store Name on Buyers' Perceptions of Product Quality: An Integrative Review," Journal of Marketing Research, 26, 351-57.

Reisman, Arnold and Xiaomei Xu (1992), "On Stages of Knowledge Growth in the Management Sciences," IEEE Transactions on Engineering Management, 39 (2), 119-28.

Riesz, Peter C. (1978), "Price Versus Quality in the Marketplace, 1961-1975," Journal of Retailing, 54, 15-28.

---- (1979), "Price-Quality Correlations for Packaged Food Products," Journal of Consumer Affairs, 13, 236-47.

Russell, Roberta S. and Bernard W. Taylor (2003), Operations Management 4th Ed. Upper Saddle River, NJ: Prentice Hall Inc.

Scitovsky, Tibor (1945), "Some Consequences of the Habit of Judging Quality by Price," Review of Economic Studies, 12 (32), 100-05.

Sethi, Suresh P. (1977), "Dynamic Optimal Control Models in Advertising: A Survey," SIAM Review, 19 (4), 685-725.

---- (1973), "Optimal Control of the Vidale-Wolfe Advertising Model," Operations Research, 21 (4), 998-1013.

---- (1974), "Some Explanatory Remarks on the Optimal Control of the Vidale-Wolfe Advertising Model," Operations Research, 22 (5), 1119-20.

Sethi, Suresh P. and Gerald L. Thompson (2000), Optimal Control Theory, 2nd Ed. Boston: Kluwer Academic Publishers.

Shapiro, Carl (1982), "Consumer Information, Product Quality, and Seller Reputation," The Bell Journal of Economics, 13 (1), 20-35.

---- (1983), "Optimal Pricing of Experience Goods," The Bell Journal of Economics, 14 (2), 497-507.

Sorger, Gerhard (1989), "Competitive Dynamic Advertising," Journal of Economic Dynamics and Control, 13, 55-80.

Sprokes, Geroge B. (1977), "New Evidence on Price and Product Quality," Journal of Consumer Affairs, 11, 63-77.

Swamidas, Paul M. (1986), "Manufacturing Strategy: Its Assessment and Practice," Journal of Operations Management, 6 (4).

Teece, D.J. (1985), "Applying Concepts of Economic Analysis to Strategic Management," in Organizational Strategy and Change, Johannes M. Pennings, Ed. San Francisco: Jossey-Bass.

Teng, Jinn-Tsair and Gerald L. Thompson (1983), "Oligopoly Models for Optimal Advertising When Production Costs Obey a Learning Curve," Management Science, 29 (9), 1087-101.

Vidale, M.L. and H.B. Wolfe (1957), "An Operations-Research Study of Sales Response to Advertising," Operations Research, 5, 370-81.

Villas-Boas, J. Miguel (1993), "Predicting Advertising Pulsing Policies in an Oligopoly: A Model and Empirical Test," Marketing Science, 12 (1), 88-102.

Weinberg, Charles B. and Doyle L. Weiss (1982), "On the Econometric Measurement of the Duration of Advertising Effect on Sales," Journal of Marketing Research, 19, 585-91.

Wernerfelt, B. (1984), "A Resource-Based View of the Firm," Strategic Management Journal, 5, 171-80.

---- (1995), "The Resource-Based View of the Firm: Ten Years After.," Strategic Management Journal, 16, 171-74.