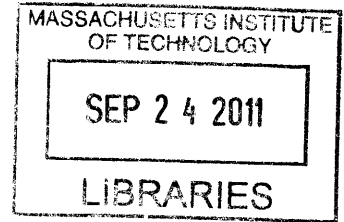


# Profit Cycle Dynamics

by

Kawika Pierson

B.S.E.E, Northwestern University, 2004



SUBMITTED TO THE SLOAN SCHOOL OF MANAGEMENT  
IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR  
THE DEGREE OF

DOCTOR OF PHILOSOPHY IN MANAGEMENT

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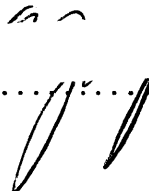
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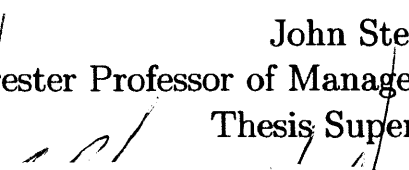
Author .....

 Sloan School of Management  
April 25, 2011

Certified by .....

  
John Sterman  
Jay W. Forrester Professor of Management  
Thesis Supervisor

Accepted by .....

  
Roberto M. Fernandez  
William F. Pounds Professor of Management  
Chairman, PhD Committee



# Profit Cycle Dynamics

by

Kawika Pierson

Submitted to the Sloan School of Management  
on April 25, 2011, in partial fulfillment of the  
requirements for the degree of Doctor of Philosophy in Management

## Abstract

My thesis consists of three essays investigating the existence, causes, and mitigation of profit cycles at an industry level. The first essay examines profit cycles by proposing that the industry-specific features of how competition acts on a firm are important determinants of how mean reversion manifests in firm earnings. The evidence suggests that because competition has inertia, caused by the time to build productive capacity specific to each industry, earnings do not smoothly revert to the mean, but instead cycle around it. Since these findings affect research that uses expected earnings models, lags of capital expenditure are used as a proxy for competition in a regression model of firm earnings and are shown to be significant determinants of the earnings reported.

The second essay seeks to explain why aggregate airline industry profits have displayed cyclical behavior since deregulation in 1978. In order to better understand the causes of these profit cycles, I build a large-scale model of the airline industry that includes more endogenous feedbacks than previous models, as well as formulations for several strategies that have been employed by airlines to mitigate the cycles. While I find that, consistent with earlier research, the delay in acquiring capacity is an important determinant of the behavior of airline profits, I also show that multiple negative feedback loops are involved in the intensity and periodicity of the profit cycle in the airline industry. Specifically, analysis of my model suggests that the growing reliance on yield management as a tool for determining ticket prices has exacerbated the volatility of airline industry profits.

The third essay focuses on the insurance industry, where the delay in building productive capacity is short. I build and analyze a parsimonious model of the property-casualty insurance industry, and show results which suggest that delays in adjusting the characteristics of underwritten insurance policies are responsible for the oscillatory behavior. Simulations where the industry increases both the target level of capital reserves, and the attention paid to the adequacy of that level, show significantly reduced profit variance.

Thesis Supervisor: John Sterman

Title: Jay W. Forrester Professor of Management



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# Chapter 1

## Earnings Mean Reversion or Cyclicity? Competition as Delayed Negative Feedback

### 1.1 Introduction

Explaining how companies become the financial statements they report is one of the central purposes of accounting research. Yet little research in accounting is focused on understanding what portion of the reported earnings number is caused by economic processes that are beyond the firm's control. If earnings are, in part, caused by the environment a firm occupies, estimates of expected earnings that do not control for that environment will be misspecified.

By studying how competition contributes to earnings mean reversion, this chapter extends our understanding of how economic forces manifest in reported earnings numbers. Current research on mean reversion does not offer testable hypotheses for how competition plays a role, because no theories have been put forward about the mechanism of competition's action. I theorize that industry membership is important for how competition affects firm earnings because each industry has a characteristic delay before firms can respond to competitive signals. I find evidence that, on an industry level, earnings display cyclicity over long time scales, and that the time necessary to build productive capacity is related to the length of this cyclical mode of industry earnings.

A recent survey of the earnings quality literature by Dechow, Ge and Schrand (2009) concludes that, regardless of the metric used to measure earnings quality, we currently cannot separate the economic processes causally related to the earnings of the firm and the accounting practices that also influence reported earnings. Specifically, they conclude:

“Existing research does not clearly distinguish the effect of a firm's fundamental earnings process on the decision usefulness (“quality”) of its earnings from the effect of the application of accounting measurement to that process.”

Even though the behavior of accounting earnings has been of interest since the work of Ball and Brown (1968), and is still actively discussed (Dechow et al. 2008 among others), Dechow, Ge and Schrand strikingly note that the confounding of economics and accounting is a gap in our understanding that must be addressed. One example of this need is their finding that many recent papers in earnings management have conclusions that are not robust to changes in the models and metrics employed by the researchers. This suggests that a model of expected earnings grounded in the economic process of earnings generation, is greatly needed for future research that uses measures of expected earnings.

Using post-1970 quarterly financial statement data from Compustat, I find that the current consensus that earnings mean reversion only exerts pressure on a firm over a short time horizon (Ball and Watts (1977); Dechow, Kothari, and Watts (1998)) is not supported by longer term autocorrelation tests of firm earnings. Exploring this result, I find evidence that a long-term cycle in firm earnings exists. By drawing on conceptual insights from engineering control theory, I argue that the mechanism of action behind competition should be expected to cause a firm that begins moving towards the mean to continue its trajectory past the mean, rather than smoothly adjusting towards it. This earnings inertia would cause firm earnings to display cyclical earnings over time, since same competitive forces act on both profitable and unprofitable firms, just as gravity acts on a pendulum regardless of which side of equilibrium it lies on.

The delayed productivity of capacity expansion means that decisions made using current expectations for profitability will have an influence on earnings far into the future. This “time-to-build” can be conceptualized as the total length of time elapsed between when a manager receives a signal that capacity should be expanded and when the capacity becomes productive. Time-to-build is not a new concept in the literature on earnings quality. Papadakis (2007) establishes that understanding time-to-build is central to understanding earnings quality by showing that the long time delay before capital investment becomes productive, compared to the short time delay inherent in the abandonment option, influences conservatism measures; however, this research is the first to hypothesize that the time-to-build delay modulates earnings mean reversion.

Using data on the time-to-build in various industries, I find support for my hypothesis that the length of the cycle in earnings at an industry level is related to the time to build productive capacity in that industry. I then document how this aspect of competition can be incorporated into earnings models by developing a regression estimate for current-period firm earnings that incorporates past, industry-specific competitive pressures. In tests of this model the proxy for competition I employ, an industry-specific lag of aggregate industry capacity expansion, is found to be a significant determinant of the variation in firm-level earnings.

These findings are important for accounting research in several ways. By expanding the literature on earnings mean reversion, the results provide a theoretical grounding for what was previously only an observed phenomenon. By identifying one of the economic forces that affects earnings, my paper provides researchers with a model that can better remedy the weaknesses highlighted by Dechow, Ge and Schrand

(2009).

Since my results give a new conceptual framework for thinking about what growth means as a proxy for competition at an industry level, there is also the potential for applications of my findings in other areas of accounting. Growth in productive capacity is a variable that has been found to be important in a variety of research settings, from asset valuation to anomalies. Re-examining those findings using this new theory could potentially be insightful. Finally, by showing that the inertia behind competition's effect on reported accounting numbers has a surprising effect on those numbers, even over a long time horizon, this paper shows a potential new line of inquiry into how a company's historical data can be used to provide insight into its future prospects.

This chapter proceeds in six sections. Section two gives background on the relevant literature. Section three discusses the generation of my hypotheses. Section four concerns the data used in my tests, and section five describes the research design. Section six presents the results, and section seven summarizes the conclusions.

## 1.2 Background and Literature Review

Beaver (1970) reports that over time earnings changes tend to revert back to the economy-wide mean. This property of earnings has been widely used in accounting research. Modern valuation formulas (Feltham and Ohlson 1995; Ohlson 1995) incorporate the effect in their future abnormal earnings forecasts. While several alternatives for these forecasts have been offered, the original papers and many others employ a random walk with drift model that includes an explicit mean reversion term. Mean reversion in earnings was cited by DeBondt and Thaler (1987) to give a rationale for what was causing the book to market anomaly they documented. When this anomaly was later studied by Fama and French (1996) they argued that a misperception of mean reversion was why investors did not understand that firms with a low market to book ratios were more likely to have large earnings changes. Earnings mean reversion was also a motivation cited by Sloan (1996) in the development of the theory behind the accrual anomaly when he proposed that even though earnings mean revert, the higher persistence of the cash flow component of earnings, relative to the accrual component, was misunderstood by investors.<sup>1</sup>

The original argument for why earnings mean revert, the fact that competition is ubiquitous in the modern economy, seems simple enough to need no further investigation. When we consider recent research findings however, several features of competition suggest themselves as potentially important to our understanding.

Fairfield et al. (2003) find that long-term growth in net operating assets results in diminishing marginal return on those assets instead of economies of scale. In the

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<sup>1</sup>It is likely that Sloan's findings on the relative persistence of the accrual and cash flow components of earnings were influenced by the effects of competition this paper analyzes. Since revenues are formed by a competitive determination of prices for a firm's product competitive cycles that are elongated by the time-to-build delay might cause the cash flow component of earnings to be more persistent than it otherwise would be.

paper it is unclear why asset growth over a long time period should cause margins to fall, however competition caused by industry level asset growth is a potential explanation. Firm level asset growth is the variable used in their tests, but all firms within an industry share common signals for profitability. This means that firms within the industry will likely make expansion decisions that are positively correlated, and so industry-level growth in net operating assets, my measure of competition, will be correlated with firm-level growth in assets. The competition from capacity building up over time would therefore act as a common force driving down margins for all firms in the industry and could be involved in causing the negative correlation between long term asset growth and return on assets that is documented in their research. Unless those competitive effects are controlled for we cannot be certain that characteristics of the marginal return are behind the result.

Another example of research that suggests the importance of competition for modeling company earnings is Zhang (2004). Zhang extends Sloan's (1996) work on discretionary accruals and finds that both the industry of the firm and its recent rate of growth play a role in determining how well the accrual anomaly performs. I conjecture that an explanation for those findings is that competition acting at the industry level industry, represented in the growth or decline of assets, is an important determinant of the path of profits. Therefore the accrual anomaly is, at least to some extent, detecting the effects of competition. Investment in productive capacity can sometimes result in accruals, and while all accruals revert to the mean, accruals that result from capacity expansion not only revert but also signal additional, future pressure on the cash flow component of earnings.

In order to operationalize the often-quoted assertion of Stigler (1963) that "Entrepreneurs will seek to leave relatively unprofitable industries and enter relatively profitable industries," we must focus on how that process occurs. A highly profitable industry not only draws capital from outside entrepreneurs, but also signals firms in the industry to invest in their own productive capacity. Productive capacity cannot be created instantly, a fact that has influenced economic thought since the development of the 'Cobweb Model' (Kaldor 1938). It takes a significant amount of time for investors to perceive a signal of high profits, trust that the signal is not noise, design the capacity, and build it, before the action of competition can subject high profits to competitive pressure.

The time to build productive capacity has been suggested as an important variable for economic analysis by many previous academics. Kydland and Prescott (1982) show that when a macroeconomic model includes a fixed delay between the initial desire for and final production of capital, the resulting effect provides a shock to the production function that can help explain business cycle fluctuations. However, the implications of this macro-economic effect for firm-level earnings was not examined in the many papers that built on their work.

To see why this delay produces testable predictions about the behavior of accounting earnings, I will begin by examining how engineering control theory understands delays. Control theory models many of its research settings as networks of feedback loops, and has developed a rigorous understanding of the behavior of feedback systems. A feedback loop occurs when a signal from one variable is transmitted through

a system, acting on other variables until the original variable is itself affected. The action of competition on a firm is a feedback loop. When earnings are abnormally high (low) competitive forces work to increase (decrease) capacity in the industry, which raises (lowers) competition and eventually lowers (raises) margins, causing earnings to be lower (higher) than they otherwise would be.

Control theory categorizes feedback loops into two types: positive and negative. The difference is straightforward: if the initial signal travels around the loop and reinforces itself by causing the initial variable to move further from equilibrium, feedback positively reinforces the original signal. If instead the initial signal causes the variable to move towards equilibrium, the feedback is restorative and the feedback loop is negative. Applying this categorization to the action of competition on profits, I suggest that the competitive feedback loop is negative, since the initially high profits act to move future profits back towards the economy wide mean.

The most important insight from control theory is that there are a limited number of ways that systems dominated by negative feedback will evolve through time. In fact, when a system is driven by a single negative feedback loop, there are only two ways that it will respond to disequilibrium (Brown 2001). If the feedback loop acts quickly, then the system will smoothly transition back towards its equilibrium. If, instead, the feedback loop includes a significant delay, the system will move in cycles around the equilibrium before eventually settling. While the discussion of exactly where the threshold between these two behaviors lies is beyond the scope of this paper, one of the key variables that determines the threshold is how strongly the signal is preserved in the course of its movement through the feedback loop. If the signal's feedback has a large effect on the original variable then even very short time delays can cause the system to overshoot its equilibrium and start oscillation, since the feedback is so forceful that it is easy for it to move the system past where it will eventually settle.

In the case of competition, not only is the time-to-build delay very long, but economic agents have very strong incentives to act on the signals they receive from the market, so the feedback effect of competition is likely to be quite forceful. If the action of competition on firm earnings is a negative feedback process with a long delay, and the power of this economic feedback loop is large, then engineering control theory would indicate that firm earnings should show evidence of cyclicity instead of gentle mean reversion.

### 1.3 Hypothesis Generation

Developing an intuitive argument for why the nature of competition leads to cycles in firm earnings requires a relaxation of some of the assumptions of market efficiency. If actors had perfect knowledge of future demand, the reaction of prices to supply, and the investment plans of their competitors, then the amount of capacity added during profitable periods would be the correct amount to bring industry profitability into balance with outside opportunities. However, since these quantities are only imperfectly known, the delay from the time to build capacity induces over-investment

by continuing to send a signal to entrepreneurs that investment will be profitable even after so much capacity is under construction that future profitability will be depressed. Once profitability starts to fall, many projects will be beyond the point where abandonment is an economically viable option, and even if continuation of the project makes no economic sense, the “sunk cost fallacy” (Kanodia et al. 1989) might make abandonment no longer psychologically viable. Furthermore, even if all capacity under construction was abandoned the moment that profits began to fall, the pressure on profits from competition would already be exigent, because excess capacity would already be causing profits to drop.<sup>2</sup>

This inertia in capacity expansion means that the competitive forces acting on a firm’s earnings will likely increase, rather than weaken, as earnings start to approach the economy-wide mean. This pressure on earnings will not abate until there is a period of capacity stagnation or contraction, and the only way that rational agents will allow capacity to adjust in this manner is if the return on assets for the industry falls far enough below the mean that no investment in the industry is warranted. Therefore I hypothesize that:

*H1 - Over a long time horizon, firm earnings show evidence of cyclicity, displaying alternating periods of positive and negative autocorrelation.*

On its own, a confirmation of this hypothesis would be an interesting extension of the literature on the mean reversion of earnings, but essential elements of the theory that motivates this hypothesis would still be unsupported. Centrally, evidence of cyclicity in firm earnings does not provide any information about whether that cycle is caused by the delay inherent in capacity building or by some other force.

There is a large body of work outside of the accounting, finance, and economics literatures that uses models grounded in the mathematics of control theory, but set in an economic context, to suggest that time-to-build is an important cause of earnings cycles. Sterman (1985) develops a macroeconomic model along the lines of Kydland and Prescott (1982), where he concludes that some very long-term macroeconomic cycles are likely to be caused by delays in “self-ordering” by engineering and construction firms. Randers (2007) shows that ocean freight shipping companies experience regular cycles in profitability, with cycle periods dependent on the length of the delay between ordering a new vessel and receiving it. Leih et al. (2001) show a similar dynamic for the airline industry, and Sterman (2000) documents several delays causing cycles in the profitability of energy exploration and extraction. These papers all focus their attention on the details of specific industries, yet they all come back to the same central mechanism when explaining the pattern of industry earnings exhibited by the data: the feedback between competition and investment, moderated by the time to build capacity.

The findings in this research stream are highly consistent, yet there has been no attempt by researchers in that literature to test whether time-to-build is related to

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<sup>2</sup>Since SG&A expenses are “sticky” (Anderson et al 2003), abandoned capacity expansion exerts pressure on other components of earnings as well. Each firm faces a type of first mover dilemma, where companies that abandon capacity expansion are “rewarded” by higher costs and larger competitors.

profit cycles cross-sectionally. If profit cycles exist, and time-to-build is an important driver of their periodicity, then estimates of the industry-specific time to build capacity should be correlated with empirical estimates of the length of the cycle in each industry's aggregate earnings.

Using the work of Kovea (2000) that documents the time-to-build across many different industries, I test the second hypothesis of this chapter:

*H2 - At an industry level, the length of time between successive peaks in the cycle of earnings will vary with the time to build productive capacity.*

If firm earnings show evidence of long-term cycles, and if there is evidence to support the hypothesis that these cycles vary with the time to build capacity in each industry, then we are left with the question of how to transform these insights into statistically and economically significant adjustments to expectation models of firm earnings. The final hypothesis in my paper proposes a regression model of the firm earnings that controls for the action of competition I hypothesize.

The change in the current competitive environment in an industry can be represented by how much new capital becomes productive in that industry. Capacity coming on line today was paid for in a previous quarter, but since the details of capacity construction vary between industries, each industry will be characterized by a different lag between capital expenditure and increased competition. Therefore, a model of expected firm earnings that controls for competitive effects should utilize industry-level capacity expansion figures that are lagged by an industry specific measure of cycle length.

One half of a cycle is how long I expect earnings to be able to persist before capacity is constructed and competition puts pressure on them to reverse.<sup>3</sup> If one half of a cycle in the past industry capital expenditure was large, then new competition will currently have a negative effect on earnings. Firms that expand capacity at the same time as the rest of their industry will, on balance, experience a higher absolute level of earnings because they will have more productive capacity during the period in question; however, increases in industry capacity will be negatively associated with firm earnings when firm capacity expansion is controlled for:

*H3 - After incorporating appropriate controls, firm earnings will be negatively related to half-cycle lags of past industry capacity expansion.*

## 1.4 Research Design

### 1.4.1 Firm Earnings Autocorrelation Spectrum

In order to examine the autocorrelation of firm earnings over a long time horizon, I estimate the following regression:

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<sup>3</sup>The choice to use a half of the cycle time rather than the full cycle time allows me to incorporate more data into the final regression, since any data points without lagged capacity expenditure data will be dropped from the sample.

$$dE_t = \alpha + \beta_1 \cdot dE_{t-1} + \epsilon \quad (1.1)$$

Where  $dE_{\{t\}}$  is the difference between current period earnings and earnings one year prior, for the firm in question, and  $dE_{\{t-1\}}$  is the same metric lagged one quarter. In this test I follow the process for running a Fama-MacBeth (1973) regression. To start, equation one is estimated once over all the firm-level data available for the first calendar quarter of the sample.<sup>4</sup> Equation one is then estimated over the data from each other calendar quarter, and I use the average of all of these estimated slopes as the final estimate for autocorrelation at that lag. The standard error of this average is used to estimate significance. The Fama-MacBeth regression procedure described above addresses the potential for time dependent, cross-sectional correlation in the error term that can arise in regressions using time series data. This series of regressions is then run forty-seven more times, once for each quarterly lag of the earnings change from two to forty-eight quarters, respectively, as shown in equations two through four.<sup>5</sup>

$$dE_t = \alpha + \beta_1 \cdot dE_{t-2} + \epsilon \quad (1.2)$$

$$dE_t = \alpha + \beta_1 \cdot dE_{t-3} + \epsilon \quad (1.3)$$

...

$$dE_t = \alpha + \beta_1 \cdot dE_{t-48} + \epsilon \quad (1.4)$$

## 1.4.2 Industry Level Autocorrelation Spectrum

Since an objective measurement of the time to build productive capacity is needed for this test, I rely on Kovea (2000) to supply part of data I use. Kovea (2000) is an International Monetary Fund paper that examines news reports that contain announcements of planned capital projects, capital projects starting construction, capital projects completing construction, and canceled capital projects. After collecting data on many projects the author separates the projects in the sample into major industry groups and estimates the time to build productive capacity in each industry. In order to match my industries with the industry designations given in Kovea (2000) I separate firms into industries according to their four digit SIC codes following 1.1.<sup>6</sup> The first step in estimating the length of the industry-level earnings cycle is to construct a time series of aggregate industry earnings changes versus the previous year. For each year and quarter of the data I summed the annual earnings

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<sup>4</sup>1970 quarter 2, since one quarter of data is needed to estimate  $dE_{t-1}$ . Each subsequent set of regressions starts one quarter later in time, since longer lags require additional data.

<sup>5</sup>The choice of 48 quarters for this test was arbitrary, no precedent exists regarding the appropriate horizon.

<sup>6</sup>Kovea does not provide the exact classifications used, whenever possible I included every 4 digit sic code within an appropriate range, but some judgment was necessary in order to maintain the face validity of the industry classifications Kovea adopts.



Number	Industry	SIC Begin	SIC End
1	Food Products	2000	2099
2	Textile Products	2200	2299
3	Lumber	2400	2450
4	Paper Products	2600	2710
5	Chemical Products	2800	2889
6	Petrol Products	2911	3010
7	Rubber	3011	3079
8	Leather	3100	3139
9	Glass and Stone	3220	3289
10	Primary Metals	3310	3410
11	Fabricated Metals	3411	3509
12	Industrial Equipment	3540	3569
13	Electrical Equipment	3570	3694
14	Transport Equipment	3711	3811
15	Measurement	3812	3840
16	Manufacturing, Other	3841	4010
17	Railroad Transportation	4011	4099
18	Freight Transportation	4100	4399
19	Water Transportation	4400	4511
20	Air Transportation	4512	4580
21	Communications	4812	4899
23	Nondurable Wholesale	5000	5199
.	Other	All other SIC codes	

**Table 1.1:** Industry Definitions Following Kovea (2000), shows the simplistic industry classifications used to subdivide firm quarters along the dimensions provided by Kovea (2000). These industries roughly follow the three digit SIC code classifications except where specific four digit industries were clearly not part of the respective group.

change, or  $dE^7$ , for each firm over all of the firms within an industry.

I use a Fourier transform algorithm to estimate the industry earnings cycle period from this data.<sup>8</sup> While autocorrelation spectrums can be used to estimate cycle lengths in time series data I used the Fourier transform because it can determine length of a cycle with greater precision, and because autocorrelation regressions at the required lags would exclude much more data from my analysis. In unreported sensitivity tests, the estimates of cycle length from autocorrelation tests were found to be highly correlated with Fourier based estimates.

A Fourier transform analyzes a time series to determine whether the data show evidence of a cycle, and also gives a measure of how strongly the data exhibits cycles of different lengths. The mathematical tool that allows a Fourier transform to detect cycles is its ability to represent the data as a sum of cyclical curves, each with a different frequency.<sup>9</sup> By taking the projection of the time series on each of these curves the Fourier transform shows how strongly each individual curve is represented in the data. A list of weights showing these relationships, known as the periodogram of the data, is the output of the Fourier transform procedure. If all of the cyclical curves listed in the periodogram were added together, then the original data would be reconstructed.

If the periodogram is significantly different from one generated by a uniform random variable, as determined by a test very similar to a T-test,<sup>10</sup> I select the period with the largest coefficient and use it as a measure of the cycle length. Using this approach I estimate the length of the cycle in aggregate earnings for each industry. I then regress these estimates against the time to build capacity for each industry with the following equation:

$$CP = \alpha + \beta_1 \cdot TtB + \varepsilon \quad (1.5)$$

Where CP is the length of the cycle in earnings that was estimated using a Fourier transform, and TtB is the time-to-build from Kovea (2000) converted into quarters.

### 1.4.3 Modeling Firm Earnings Under Competition

A model of how competition affects firm earnings that only looks at time-to-build is overly simple. First, ignoring the fact that earnings are persistent would ignore one of the most well documented time series properties of earnings (Kormendi and Lipe 1987

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<sup>7</sup>Earnings for the given year and quarter minus earnings for the same quarter one year prior.

<sup>8</sup>Fourier transform methods have been used in many papers for the analysis of time series data in finance. They are widely used for options valuation (Carr and Madan 1998), some characterizations of conditional expectations (Bierens 1982), and for tests of heteroskedasticity in multiple regression analysis (Robinson 1991).

<sup>9</sup>Cycle frequency is the mathematical inverse of cycle period. The period of a cycle is the length of time elapsed while completing one cycle while frequency is the number of cycles completed in a set length of time.

<sup>10</sup>The periodogram from each industry's Fourier transform is compared to the periodogram of a uniform random variable and Bartlett's test for the likelihood that the time series is white noise is performed.

among others). Including prior year earnings in my model for firm earnings does not detract from my assertion that the model estimates the component of firm earnings that is a result of economic forces. The large number of firm quarters included in the analysis ensures that the model estimates only the component of firm earnings caused by the persistence of the earnings generating process that is common across firms. Year-on-year lags of firm earnings are therefore used as a control variable in the model.

Firms should also be expected to generate a certain average return on assets. If the persistence of earnings does not completely capture changes in the normal expectation for this return, then lagged book value will be an important economic determinant of earnings. Over time workers become more efficient with assets they use. Automation and other technologies have driven further gains in productivity that will be captured with this control. Therefore, I include the one year lag of book value in my firm earnings model and propose that it will be positively related to current period earnings when earnings persistence is controlled for.

Fama and French (2000) document many statistical properties of earnings mean reversion. Among these is the finding that firms with higher abnormal earnings experience faster mean reversion. In light of my theory that competition is the underlying cause of mean reversion, their finding suggests that competition acts more strongly on firms in more profitable industries. My model of firm earnings includes a lagged value of industry return on assets to test whether this variable has incremental explanatory power in the presence of my competition proxy.

For tests of hypothesis three firms are organized into industries following the categorization first presented by Fama and French (1997). Firm-level annual earnings changes for all firms within each Fama-French industry are summed, and a time series for aggregate industry earnings changes is constructed. This time series undergoes a Fourier transform analysis very similar to those in tests of H2 in order to determine the length of the earnings cycle in each industry.<sup>11</sup>

The indicated cycle period is divided by two, rounded up to give a whole number of quarters, and recorded. While using the full cycle time may make more conceptual sense, the half cycle time allows for twice as much data to be included in my regression, and only influences the expected sign on the effects I test, not the theoretical basis for them. After the half-cycle periods are recorded, I estimate the following regression across all firm quarters that have sufficient data:

$$\begin{aligned}
 Earn_t = \alpha + \beta_1 \cdot Comp_{t-c} + \beta_2 \cdot Earn_{t-4} + \\
 \beta_3 \cdot Book_{t-4} + \beta_4 \cdot FCap_{t-c} + \beta_5 \cdot IROA_{t-c} + \varepsilon
 \end{aligned}
 \tag{1.6}$$

The dependent variable  $Earn_t$  is the reported level of firm net income, the independent variable  $Comp_{t-c}$  is the proxy for competition measured by the  $c$  quarter lag of industry capital expenditure scaled by lagged total industry assets; where  $c$  is the

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<sup>11</sup>The difference between the two analyses is that cycle periods longer than 48 quarters are not considered when selecting the industry cycle period for tests of H3. These long periods are excluded in order to increase the data available to the final regression, though only one industry's cycle period estimate is changed.

industry specific half cycle time referenced above.  $Earn_{t-4}$  is the level of firm net income lagged one year,  $Book_{t-4}$  is the book value of total assets lagged one year,  $FCap_{t-c}$  is the total firm capital expenditure lagged  $c$  quarters, and  $IROA_{t-c}$  is the industry return on assets lagged  $c$  quarters. For sensitivity analysis the regression is estimated twice, once with Newey-West standard errors and once with a Fama-MacBeth analysis. This approach is suggested by the findings of Peterson (2009) that Newey-West standard errors are generally unbiased in the presence of both firm and time effects.

## 1.5 Sample Selection

My sample takes quarterly data from all firms in the Compustat database with non-missing values of earnings, total assets and capital expenditure for the period from 1970 until 2009. The sample starts in 1970 because capital expenditures are not recorded for the majority of firms until Compustat begins including cash flow statement data. The total sample consists of 906,828 firm quarters of data. For tests of hypothesis one the number of firm quarters declines to a minimum of 205,759 for the longest autocorrelation lag due to the declining number of firms who have the sufficient number of consecutive firm quarters of data. For tests of hypothesis three the number of firm quarters of data that are useable falls to 690,224, since lagged values of variables are also required in that analysis.

Utilities are excluded from my analysis of hypothesis two because Kovea (2000) notes that his estimate for the time-to-build in that industry was skewed by the industry's tendency to put partially completed projects on hold without announcing this until the project was fully completed. He finds that utilities projects are over 40% more likely than other projects to be delayed for long periods of unknown duration, causing this data point to be a troublesome outlier in his analysis as well as mine.

## 1.6 Results

### 1.6.1 Evidence that Long Horizon Firm Earnings are Cyclical

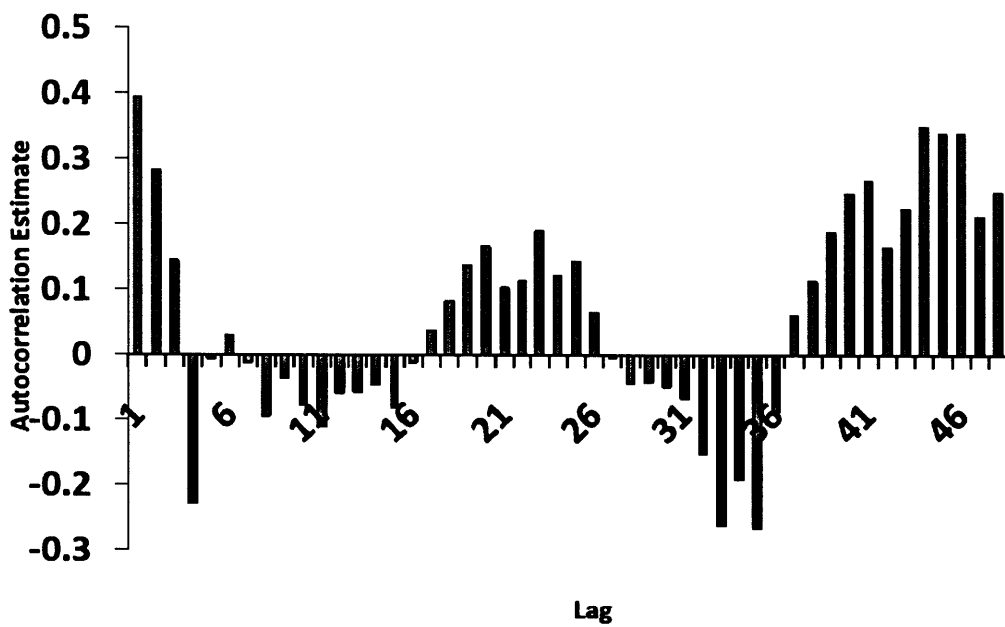
Table 1.2 presents the results of the regression tests of hypothesis one, while figure 1-1 is a graph of the estimated autocorrelations. There is considerable evidence from the regression results that the long horizon autocorrelations of firm earnings exhibit periods of a positive relationship followed by periods of a negative relationship. While the positive autocorrelations are in general larger and more statistically significant, firm earnings tend to grow, so a skew towards positive autocorrelation is expected.<sup>12</sup>

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<sup>12</sup>I do not believe that the observed increase in the strength of the autocorrelations towards the later lags indicates that the effect is somehow stronger for longer lags in earnings. Instead this slight increase in the magnitude of autocorrelation estimates is likely caused by the survivorship bias inherent in running a regression that requires so many consecutive quarters of firm earnings data. Any firm that lasts for such a long time will have standardized its production, and will

Lag	Mean	Median	25th Pctl	75th Pctl	Std Error	t Value
1	<b>0.39</b>	<b>0.32</b>	<b>0.13</b>	<b>0.58</b>	<b>0.04</b>	<b>11.12</b>
2	<b>0.28</b>	<b>0.18</b>	<b>0.04</b>	<b>0.42</b>	<b>0.05</b>	<b>6.2</b>
3	<b>0.14</b>	<b>0.06</b>	<b>-0.03</b>	<b>0.29</b>	<b>0.03</b>	<b>4.98</b>
4	<b>-0.23</b>	<b>-0.26</b>	<b>-0.51</b>	<b>-0.03</b>	<b>0.04</b>	<b>-6.34</b>
5	-0.01	-0.02	-0.14	0.16	0.03	-0.23
6	0.03	-0.01	-0.15	0.14	0.03	0.86
7	-0.01	-0.01	-0.20	0.13	0.04	-0.28
8	<b>-0.09</b>	<b>-0.06</b>	<b>-0.24</b>	<b>0.10</b>	<b>0.04</b>	<b>-2.13</b>
9	-0.04	-0.02	-0.25	0.12	0.04	-0.99
10	<b>-0.08</b>	<b>-0.01</b>	<b>-0.19</b>	<b>0.10</b>	<b>0.04</b>	<b>-1.95</b>
11	<b>-0.11</b>	<b>-0.02</b>	<b>-0.20</b>	<b>0.08</b>	<b>0.05</b>	<b>-2.1</b>
12	-0.06	-0.02	-0.18	0.10	0.06	-1.03
13	-0.06	-0.05	-0.24	0.07	0.04	-1.35
14	-0.05	-0.03	-0.20	0.07	0.05	-1.01
15	-0.08	-0.02	-0.23	0.09	0.05	-1.64
16	-0.01	-0.03	-0.16	0.11	0.06	-0.19
17	0.04	0.02	-0.12	0.19	0.05	0.72
18	0.08	0.04	-0.08	0.22	0.04	1.85
19	<b>0.14</b>	<b>0.05</b>	<b>-0.09</b>	<b>0.22</b>	<b>0.07</b>	<b>2.05</b>
20	<b>0.17</b>	<b>0.06</b>	<b>-0.09</b>	<b>0.30</b>	<b>0.06</b>	<b>2.97</b>
21	<b>0.10</b>	<b>0.06</b>	<b>-0.10</b>	<b>0.28</b>	<b>0.05</b>	<b>1.96</b>
22	<b>0.11</b>	<b>0.03</b>	<b>-0.14</b>	<b>0.26</b>	<b>0.05</b>	<b>2.21</b>
23	<b>0.19</b>	<b>0.03</b>	<b>-0.11</b>	<b>0.28</b>	<b>0.06</b>	<b>3.28</b>
24	0.12	0.04	-0.14	0.21	0.06	1.87
25	<b>0.14</b>	<b>0.03</b>	<b>-0.12</b>	<b>0.43</b>	<b>0.06</b>	<b>2.47</b>
26	0.06	0.02	-0.16	0.23	0.05	1.33
27	0.00	0.00	-0.27	0.17	0.05	-0.09
28	-0.04	-0.03	-0.25	0.19	0.06	-0.73
29	-0.04	0.02	-0.20	0.21	0.06	-0.67
30	-0.05	0.01	-0.26	0.23	0.08	-0.62
31	-0.07	-0.02	-0.29	0.24	0.10	-0.66
32	-0.15	-0.02	-0.39	0.21	0.13	-1.21
33	<b>-0.26</b>	<b>-0.08</b>	<b>-0.47</b>	<b>0.15</b>	<b>0.13</b>	<b>-2.02</b>
34	-0.19	-0.07	-0.46	0.17	0.10	-1.84
35	<b>-0.27</b>	<b>-0.01</b>	<b>-0.48</b>	<b>0.23</b>	<b>0.12</b>	<b>-2.13</b>
36	-0.09	0.05	-0.29	0.24	0.15	-0.57
37	0.06	0.07	-0.21	0.37	0.10	0.58
38	0.11	0.10	-0.14	0.43	0.08	1.33
39	<b>0.19</b>	<b>0.12</b>	<b>-0.18</b>	<b>0.57</b>	<b>0.07</b>	<b>2.59</b>
40	<b>0.25</b>	<b>0.15</b>	<b>-0.15</b>	<b>0.49</b>	<b>0.11</b>	<b>2.29</b>
41	<b>0.27</b>	<b>0.14</b>	<b>-0.10</b>	<b>0.52</b>	<b>0.09</b>	<b>2.98</b>
42	0.17	0.08	-0.16	0.44	0.11	1.57
43	<b>0.22</b>	<b>0.13</b>	<b>-0.14</b>	<b>0.47</b>	<b>0.11</b>	<b>1.95</b>
44	<b>0.35</b>	<b>0.10</b>	<b>-0.22</b>	<b>0.48</b>	<b>0.13</b>	<b>2.63</b>
45	<b>0.34</b>	<b>0.09</b>	<b>-0.19</b>	<b>0.55</b>	<b>0.14</b>	<b>2.4</b>
46	<b>0.34</b>	<b>0.10</b>	<b>-0.22</b>	<b>0.66</b>	<b>0.15</b>	<b>2.28</b>
47	0.21	-0.01	-0.39	0.45	0.17	1.23
48	0.25	0.06	-0.35	0.52	0.15	1.62

**Table 1.2:** This table presents the results from 48 sequential Fama-MacBeth regressions, each using a different lag length, but all measuring the autocorrelation of firm earnings changes at that lag. Statistically significant entries are shown bold, with reported Fama-MacBeth t-statistics in the far right column.



**Figure 1-1:** This figure shows the results from the first column of table 1 presented as a time graph. The x-axis is the autocorrelation lag length in quarters, while the y-axis is the magnitude of the average autocorrelation estimated by Fama-MacBeth regressions on firm earnings for that lag length.

Figure 1-1 shows the pattern I detect in firm-earnings autocorrelations. For every case, except the four quarter lag, once the autocorrelations become negative they tend to stay negative and once the autocorrelations become positive they tend to stay positive. The results are so consistent in this regard that the estimates from lag seven through lag thirty-seven consist of exactly ten negative autocorrelations, followed by exactly ten positive autocorrelations, and a final ten negative autocorrelations. This evidence suggests that the autocorrelation structure that originally motivated the theory of earnings mean reversion may actually be the short-term portion of a much longer term pattern in firm earnings.

## 1.6.2 Evidence that the Cycle Length Varies with Time-to-Build

Table 1.3 reports industry-level estimates of the primary cyclical mode of aggregate industry earnings changes, as estimated by the Fourier transform analysis, along with the estimates of time-to-build from Kovea (2000) and results from Bartlett's test for white noise. Table 1.4 presents the results of the OLS regression for the correlation between these two sets of estimates.

The results of Bartlett's test for the likelihood that a data set is white noise show that for the vast majority of industries the time series of aggregate industry earnings changes is almost certainly not noise. Only three industries: freight transportation, fabricated metals, and nondurable metals fail to differentiate their behavior from a uniform random variable at the 1% level, and only the time series for freight transportation is more likely to be white noise than not to be.

The results of the regression testing whether the time-to-build is correlated with the length of the cycle in aggregate industry earnings indicate a statistically significant, positive relationship between the two variables. In unpublished tests with the constant of the regression suppressed the slope estimate on quarters to build is almost exactly two.<sup>13</sup> These findings are consistent with hypothesis two, suggesting that the time to build capacity is an important determinant of the length of the cyclical mode of the earnings of that industry. As a sensitivity test, autocorrelation regressions were also used to detect the length of the cycle in aggregate industry earnings. The results generally agree with the results of the Fourier transforms (65%  $R^2$ ), but do not load significantly in the regression.

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have a "proven" method for responding to competitive pressures. If competition causes long-period earnings autocorrelation then firms that standardize their response to competition will be expected to show a relatively stronger autocorrelation of earnings across time.

<sup>13</sup>One finding from the modeling papers discussed in section two was that the peak to peak cycle time of each industry was usually on the order of twice the time-to-build, since profitability can persist for one "time-to-build" after competition starts to influence profits and then it takes approximately one more "time-to-build" for actors to perceive that profits have fallen, construction of new capacity to be finished or canceled, and demand to rise once again. This relationship can vary considerably however, so I do not include this as an explicit hypothesis but only use it as a reality check for my results.

Code	Industry	Quarters to Build	Cycle Period Estimate	White Noise P-Value
1	Food Products	8	6.666	<0.001
2	Textile Products	8	8.75	<0.001
3	Lumber	10	9.9286	0.0088
4	Paper Products	7.67	15.77	<0.001
5	Chemical Products	7.67	7.55	<0.001
6	Petrol Products	7.67	2.78	0.0011
7	Rubber	4.33	8.625	<0.001
8	Leather	7.67	27.8	<0.001
9	Glass and Stone	6	11.58	0.2801
10	Primary Metals	12.33	35	<0.001
11	Fabricated Metals	4.67	6.7619	0.5
12	Industrial Equipment	6	16	<0.001
13	Electrical Equipment	8	14.4	<0.001
14	Transport Equipment	9.33	8.6875	<0.001
15	Measure	8.33	29.2	<0.001
16	Manufacturing, Other	6	15.77	<0.001
17	Railroad Transportation	6	8.875	0.01
18	Freight Transportation	7.67	2.58	0.1935
19	Water Transportation	8.33	13.4	<0.001
20	Air Transportation	8	34.5	<0.001
21	Communications	8	13.9	<0.001
23	Nondurable Wholesale	12.33	36.25	0.0977
.	other	8	31.8	<0.001

**Table 1.3:** This table presents the data from Kovea (2000) for the empirically estimated number of quarters to build in each industry classification under the “Quarters to Build” column. In the “Cycle Period Estimate” column are most likely cycle periods returned by the Fourier transform algorithm performed on aggregate industry earnings for each of those industries. The final column, labeled “White Noise P-value” is the estimate produced by Bartlett’s test for white noise of the percentage chance that the time series evaluated for each industry was produced by a uniform random variable.

Variable	Parameter Estimate	Standard Error	t-stat	R <sup>2</sup>
Constant	-6.93	7.9153	-0.875	29.37%
Quarters to Build	2.83	0.9822	2.884	

**Table 1.4:** This table documents the results of a linear regression of the time-to-build estimates from Kovea (2000) and the industry earnings cycle lengths produced by the Fourier transform algorithm. “Quarters to Build” is the data from Kovea and served as the independent variable.



stats	$Earn_t$	$Earn_{t-4}$	$Book_{t-4}$	$FCap_{t-c}$	$Comp_{t-c}$	$IROA_{t-c}$
N	690224	690224	690224	690224	690224	690224
mean	21.39	21.35	3556	64.45	0.0322	0.01175
p50	0.726	0.735	140.5	0.765	0.02195	0.00958
iqr	8.4315	7.827	872.1	9.846	0.04054	0.01161
var	100410	76848	1.08E+09	253116	0.00172	0.00933

**Table 1.5:** This table gives the summary statistics for all of the firm quarters used in tests of hypothesis three. The dependent variable  $Earn_t$  is the reported level of firm net income, the variable  $Earn_{t-4}$  is the same metric lagged one year,  $Book_{t-4}$  is the book value of total assets lagged one year,  $FCap_{t-c}$  is the total firm capital expenditure lagged  $c$  quarters; where  $c$  is the industry specific half cycle time estimated by Fourier transform,  $Comp_{t-c}$  is the industry capital expenditure lagged  $c$  quarters and scaled by lagged total industry assets, which is the proxy for competition central to my analysis, and  $IROA_{t-c}$  is the industry return on assets lagged  $c$  quarters.  $N$  is the number of observations in the sample, mean is the arithmetic mean of all observations, p50 is the median, iqr is the inter-quartile range, and var is the variance.

### 1.6.3 Evidence that Past Industry Capacity Expansion Helps Explain Current Firm Earnings

Summary statistics for the variables included in tests of hypothesis three are presented in table 1.5. The summary statistics are generally unremarkable. Both firm earnings and book values show the large variances and shifted means expected from a Pareto distribution. Average firm capital expenditure is many times larger than earnings, though it remains a small fraction of book value. The percentage growth in industry capacity in any quarter tends to be small and positive, though the inter-quartile range suggests that it is quite variable.

Table 1.6 presents the results of the panel regression that tests whether my proxy for competition is significantly related to firm earnings levels. The Newey-West standard errors are reported as well.

All estimated coefficients load significantly at the 1% level and in their predicted directions, except for lagged industry return on assets which loads significantly at the 1% level but in the direction opposite from the one that would be implied by my reading of Fama-French (2000). The implication of this result is that the persistence of an industry's level of profitability acts more strongly to sustain firm earnings than as a signal to outside investors that drives profits towards the mean, once industry level capacity expansion is included in the analysis.

The coefficient estimate for lagged industry capacity expenditure provides evidence in support of my theory of competition, and supports hypothesis three. Carefully chosen lags of past industry capacity expansion are statistically significant determinants of future expected firm earnings, given appropriate controls.

In order to gain some insight into the economic significance of these results, consider that the regression estimates imply that the average firm in my sample earns almost 9.6 million dollars per quarter, plus 35% of their prior year earnings. Produc-

$Earn_t$ on:	Coefficient	Newey-West Std. Err.	t	$P >  t $	adj R <sup>2</sup>
constant	9.59815	0.7088889	13.54	<0.001	13.86%
$Earn_{t-4}$	0.3529226	0.0470316	7.5	<0.001	
$Book_{t-4}$	0.0006424	0.0002178	2.95	0.003	
$FCap_{t-c}$	0.0644838	0.0069436	9.29	<0.001	
$Comp_{t-c}$	-74.6179	12.35903	-6.04	<0.001	
$IROA_{t-c}$	19.03536	3.972201	4.79	<0.001	

**Table 1.6:** This table presents regression results from tests of hypothesis three. Constant is the constant of the regression. The dependent variable  $Earn_t$  is the reported level of firm net income, the variable  $Earn_{t-4}$  is the same metric lagged one year,  $Book_{t-4}$  is the book value of total assets lagged one year,  $FCap_{t-c}$  is the total firm capital expenditure lagged c quarters; where c is the industry specific half cycle time estimated by Fourier transform,  $Comp_{t-c}$  is the industry capital expenditure lagged c quarters and scaled by lagged total industry assets, which is the proxy for competition central to my analysis, and  $IROA_{t-c}$  is the industry return on assets lagged c quarters. The standard errors reported are Newey-West standard errors.

tive assets can be expected to generate a very small additional return per dollar after they have been used to produce this level of earnings.

Investment made one half-cycle ago on productive capital offers an expected return on assets of 6.4% on average, but industry capital expenditure of just 1% of total industry assets at the same point in the past is expected to result in a loss of over \$740,000 to the average firm. While it is true that for every 1% of profitability enjoyed by the firm's industry at that earlier date, the average firm can expect to generate an additional \$190,000, the summary statistics show that the magnitude of lagged industry capacity expansion is generally much larger than the size of lagged industry return on assets. Overall, the economic interpretation of the regression estimates indicates that the effect of competition on firm earnings is significant and negative further supporting hypothesis three.

As an unreported sensitivity test, I also estimate the regression using a Fama-MacBeth procedure. Under this alternate design all variables load significantly and in the same direction as in the panel regression, though the relative sizes of the coefficient estimates change. Also, the economic significance of the estimates is qualitatively similar to those reported above.

## 1.7 Conclusion

This chapter is a first step towards specifying what portion of the reported earnings number can be attributed to economic processes as opposed to accounting processes, with the hope of informing the literature on accounting quality. While my findings fall short of settling the question posed by Dechow, Ge and Schrand (2009), they provide a solid basis for future work on the subject, and inform our understanding of earnings mean reversion, competition, and the time-series properties of earnings.

I find that competition, represented by lagged industry capacity expansion, has a

measurable effect on reported earnings. This suggests that the competitive process I hypothesize to be behind earnings mean reversion may induce patterns in earnings that evolve over time horizons much longer than those considered previously.

In showing that industry-level profit cycle lengths are related to the time to build productive capacity, I further support my argument that industry-specific details competition are important for our understanding of accounting earnings. The regression model used to test Hypothesis Three provides a method for researchers to incorporate this aspect of the economic environment in future modeling of earnings expectations, and documents an additional control to consider in other research settings where the economic forces influencing firm earnings are of potential importance.

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## Chapter 2

# Cyclical Dynamics of Airline Industry Profits

### 2.1 Introduction

Researchers in system dynamics have studied cyclicity in economic settings for decades (Forrester 1965, Forrester et. al. 1976), and have largely concluded that profit cycles are caused by the delay in the negative feedback loops controlling the adjustment of capacity. Because of the very long delays often associated with capacity building, the salience of productive capacity to managers, and the high fixed costs of capacity it is not surprising that capacity adjustment is a major determinant of profit dynamics, however these same observations often serve as an obstacle to the implementation of system dynamics research, as managers can be reluctant to accept that such important decisions could have been mistakes.

Profit cycle models that are sufficiently endogenous to test competing hypotheses for the cause of the cycles, proposed by defensive managers, have been well accepted in the past (Randers 2007). Numerous endogenous feedback loops can be difficult to include in a model though, because data is often not publicly available for the most important stocks. Academics who want to parametrize their models against historical data usually must trade off between making models that are less realistic than desired or accepting data from private sources that will not allow the model structure to be published.

The airline industry is an excellent setting for research on long term profit cycles because the government requires airlines to report highly detailed information about their operations, and makes all of the data available to the public. By avoiding private sources for data, while still being able to show how my model matches the historical path for the industry-level stocks, I provide an “open-source” feedback-rich model that system dynamics and airline industry professionals can use to better understand the dynamics of earnings in the industry.

Airlines are also advantageous as a research setting because of their importance. The airline industry provides the transportation that allows people across the nation to increase their productivity and enjoy their leisure time. Yet despite how important

airlines are, robust strategies for creating consistent profitability within the industry have been elusive. In fact, profitability cycles have been experienced by the industry since deregulation, fluctuating with a distance between peaks of around ten years (Hansman and Jiang 2000). Industry analysts and experts are not blind to this pattern of behavior. Like their peers in other cyclical industries, they consistently argue either that specific events were the cause of the cycle turning points or that new strategies will dampen the cycle in the future. These arguments persist in the face of a history of strategies, such as leasing, yield-management, and mothballing, that have failed to stabilize aggregate profits.<sup>1</sup>

In this paper I build a model of the airline industry that addresses the question of why airline industry profits cycle. Even though this question has been addressed previously by the system dynamics literature, most notably by Liehr et al (2001) and Lyneis (2000), I extend those efforts by including many endogenous feedback loops left out of earlier models, including price setting, workforce dynamics, and aggregate demand fluctuations. Including these feedback loops in the model allows me to more closely match the history of reported profits, and better test policies for controlling the cycle. The model also includes structures that approximate the effects of yield management, mothballing, and ancillary fees in an effort to address the effect of existing strategic decisions on profit cycles.

The results of the model suggest that even though capacity adjustment can cause profit instability, compensating feedback loops from capacity to demand, costs, and price work to perpetuate a cycle even if capacity is non-cyclical. In particular I find evidence to suggest that the historically fierce competition over price may be primarily to blame for the severity of airline industry profit cycles, as policy levers controlling the strength of the feedback loops involving price are effective for eliminating profit variance. Specifically, yield management, or a strong feedback from load factor to ticket price, is found to increase the average level of profits but also their variance. Model runs that de-emphasize yield management in favor of feedback loops from profit onto price show lower average profit but also much lower variance, and do not alter the path of ticket prices significantly.

Additionally, the model offers an extension of the standard capacity control formulation that ensures no steady state error under a constant growth path, and a non-conserved co-flow formulation of average worker tenure with simple layoff and hiring. is my documentation of a macro-enabled model structure for simulating the data reporting process that can be used in any setting where a model is fit to historical data points. This structure can be adjusted to arbitrary data reporting lengths, and avoids matching approximately continuous simulation outputs with more discrete historical data.<sup>2</sup>

I proceed from the introduction in ten sections beginning with section 2, which introduces the data used in the model. Section 3 reviews the core dynamic hypoth-

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<sup>1</sup>Yield, the industry term for dollars per revenue passenger mile, and price, a more general term for the concept, are used interchangeably in this paper.

<sup>2</sup>Reporting periods that are not divisible by the time step will cause the structure to believe that data reporting never occurs, however good modeling practice ensures that this will not happen in practice.

esis for the industry. Section 4 discusses my decisions on where to place the model boundary. Section 5 gives details on the model structure. Section 6 concerns various methods of model validation, including partial model tests to help show the rationality of the decision makers modeled. Section 7 discusses the parameter estimation process. Section 8 shows the final model fit to historical data. Section 9 evaluates policy recommendations, and section 10 concludes.

## 2.2 Airline Industry Data

Data is publicly available for the airline industry over a long time horizon, making it an ideal industry in which to construct a system dynamics model. The data I use comes primarily from the Air Transport Association (ATA), the nation's oldest and largest airline trade association. They gather and store historical records of data from the Bureau of Transportation Statistics (BTS) and perform several transformations on it that lend themselves well to system dynamics modeling. They publish airline ticket prices as an industry wide average in dollars per seat mile rather than the index that is published by the BTS, and calculate the average wage of a worker in the industry from the filings of each individual carrier. Some data is also collected from MIT's Airline Data Project (ADP) though the ATA is the primary source.<sup>3</sup>

The model uses time series data on airline available seat miles (capacity), revenue passenger miles (demand), average ticket price per revenue passenger mile (price), average wage per worker (salary) and aggregate operating profit (profit) from 1977 until 2010.<sup>4</sup> While operating costs are available as a separate data item, the data for operating profit does not equal the data for operating revenue minus the data for operating costs. Because of this I make the simplifying assumption that "historical" operating costs equal that they would have had to have been in order to produce the historical profit and revenue. When I match my simulated costs to the data, I match to this time series rather than the time series of operating costs available publicly.<sup>5</sup>

### 2.2.1 Exogenous Inputs

There are many exogenous inputs to the model: population, domestic GDP, world GDP, the consumer price index, the producer price index excluding food and energy, jet fuel prices, the national average wage, fractional unemployment, airline industry employee productivity, the fuel efficiency of the airlines, and total ancillary fees collected by airlines. Population comes from the Census Bureau, while yearly GDP data for both the U.S. and the world is taken from World Bank website and measured in real, year 2000 dollars per capita.<sup>6</sup> The CPI, the PPI, the national average wage and

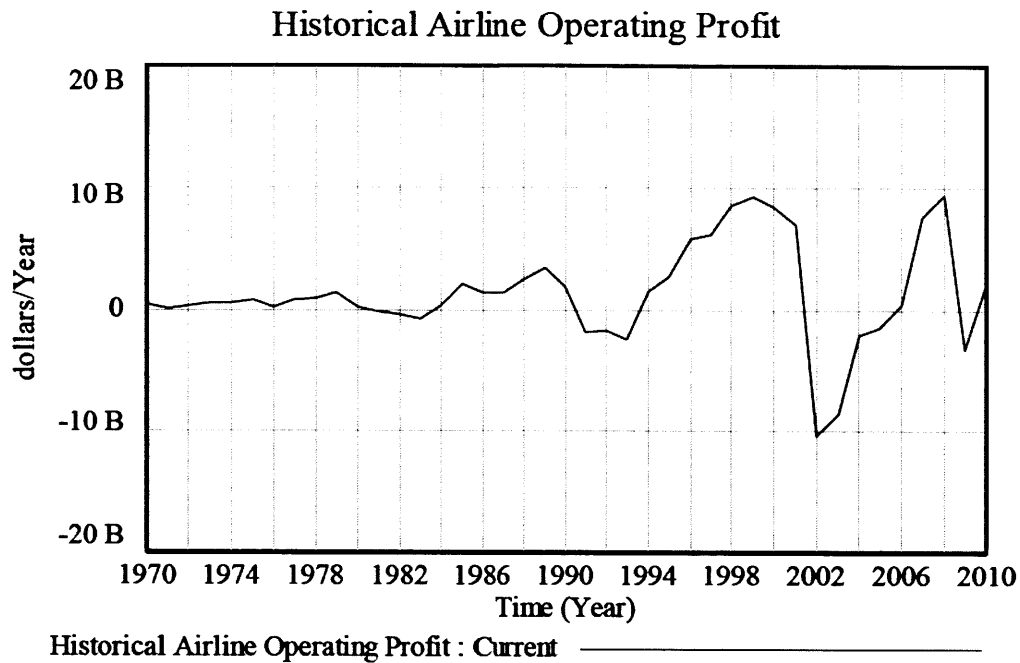
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<sup>3</sup>ATA - ([www.airlines.org](http://www.airlines.org)); ADP - (<http://web.mit.edu/airlinedata/www/default.html>)

<sup>4</sup>Average wage includes all salary, benefits and other compensation.

<sup>5</sup>"Operating" expenses as reported to the SEC include items such as depreciation, marketing, merger costs, code sharing expenses, and other costs. For the most part these details were excluded from the model, or modeled as a part of general variable costs.

<sup>6</sup>GDP per capita should be expressed in "real" dollars, rather than the nominal dollars used in the rest of the model because using real GDP better captures the effect of economic expansion



**Figure 2-1:** Historical Aggregate Airline Operating Profit

the unemployment time series come from the U.S. Department of Labor's Bureau of Labor Statistics. Jet fuel prices per gallon, employee productivity, and fuel efficiency are obtained from the ATA. Ancillary fees come from the ADP.

## 2.3 Causal Structure

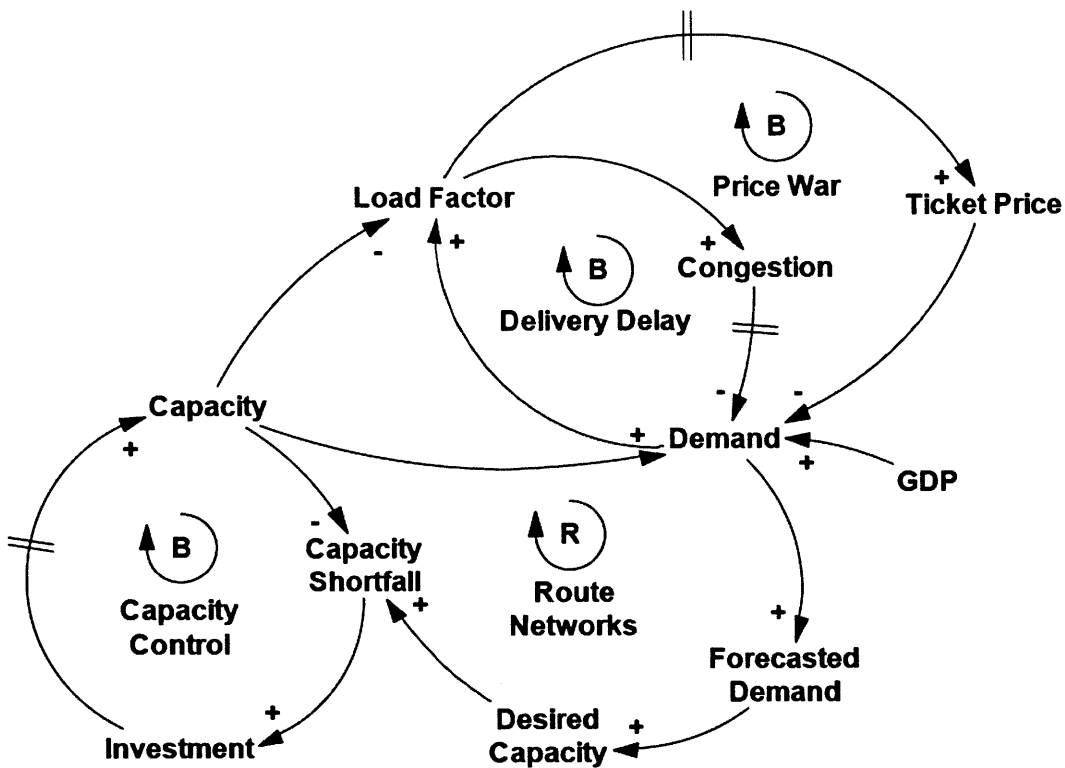
The reference mode for industry profit exhibited in the data is that even though demand for airline seat miles grows exponentially, profits follow an oscillatory path. Because profit cycles in many settings are caused by a misperception of the delayed negative feedback controlling the capacity acquisition decisions of the industry (Meadows 1970) this feedback will lie at the heart of my model. There are several other balancing feedback loops that complicate this dynamic in the airline industry however, and these loops will be included as well.

My dynamic hypothesis for the evolution of the profit cycle in the airline industry can be explained through the interaction of these feedback loops. Suppose that demand was initially high relative to available capacity, and the industry was experiencing high load factors as well as high profitability. The industry would collectively add capacity in this situation so as to maximize profit, but all actors in the

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on demand. Inflationary effects should have little bearing on airline demand independent of ticket price, and demand is the only variable affected by GDP.





**Figure 2-2:** Simplified Causal Loop Diagram for the Airline Industry

industry face an average delay of two years before their new aircraft orders become actual planes. The high load factors continue to drive prices and profits up, making orders for new planes rise further. In the interim, since capacity is insufficient, airline passengers experience congestion and overbooking causing them to perceive air transportation as less attractive than other alternatives.

Once the new planes that were ordered during this period of high profits arrive they immediately add to both the revenue and the costs of the industry. Ordering that occurred during the highly profitable period of the cycle cannot be canceled even though load factors begin to fall, and as more planes are added to capacity load factors fall further. Low load factors cause some of these planes to not produce sufficient revenue to make operating them profitable, and previously high congestion has caused some consumers to avoid air travel. As these dynamics play out airlines will compete on price. As capacity grows and prices fall airlines experience a period of high costs and low revenue that causes profits to suffer. Over time demand will grow and this capacity will be utilized, but if similar actions are taken during the next boom the structure of the system will perpetuate the cycle.

## 2.4 Model Boundary

The model boundary is intentionally broad, though exogenous effects are important in many of its sectors. Demand is partially exogenous, with the growth path being driven by population and a combination of both U.S. and world gross domestic product. I chose to exclude the feedback from air transportation to the growth of GDP because it is complex, small, and poorly understood. Wages are also influenced exogenously by the national average wage, the unemployment rate and the Consumer Price Index. The effect of airline employment dynamics on national unemployment and the national average wage is likely relatively small, and developing a macroeconomic model of employment and wages would be prohibitively complex given my model's purpose.

I drive the cost sector of the model with several exogenous inputs, including the producer price index, jet fuel efficiency, and the cost of jet fuel. Of all of the simplifying assumptions I make, the choice to exclude the feedback between airline capacity and jet fuel prices is potentially the most likely to raise questions about validity. While it may seem important to include airline industry jet fuel consumption in the determination of jet fuel prices, the supply of jet fuel is actually relatively price inelastic (Kendix & Walls 2010). When crude oil is refined into usable products each barrel is cracked into a fixed fraction of different grades of petrochemical materials. Jet fuel is made from a very small part of this material, and so any fluctuations in refining activity due to changes in the price of crude oil will be the largest influence on the price of jet fuel (Dahl 1994). Demand for jet fuel is more price elastic, but demand fluctuations will not feed-back onto the price of fuel substantially.

## 2.5 Model Structure

In order to compute the profit of the industry my model is organized into four broad sectors: Capacity, Demand, Prices and Costs. Since demand is measured in revenue passenger miles per year, and revenue passenger miles multiplied by the price in dollars per mile gives the revenue for the industry revenue minus costs then computes profit.

Capacity is set using a stock control formulation that is adapted from the standard one in the system dynamics literature (Sterman 2000). The stock of airline industry capacity is compared to the desired capacity of the industry and this indicated change is adjusted for the supply line of capacity and the forecasted growth of the industry. The forecasted growth rate is determined using a standard third-order forecasting structure (Sterman 2000). The stock and flow chain of productive capacity and capacity being constructed use third order material delays with total delay times of two years for the construction of planes and thirty years for the average service life of planes. I include both mothballing of capacity and cancellation of orders for planes as endogenous variables in the model, and orders for planes are adjusted for planes returning from storage. I assume that each plane flies a constant number of seat-miles per year in order to arrive at the total available seat miles of the industry.

Demand per person is a linear function of both domestic and international Gross Domestic Product, with separate slopes<sup>7</sup>. The level of per capita demand indicated is then multiplicatively influenced by several pressures: prices normalized by the initial ticket price adjusted by inflation<sup>8</sup>, the recent change in airline capacity<sup>9</sup>, and congestion as perceived by the public. Congestion is measured as the ratio of the current load factor to the “normal” industry load factor. Since deregulation the load factor where consumers perceive air travel to be congested has increased due to technological advances. Since I have no basis on which model these effects I model “normal” load factor as the line that best fits historical load factor.<sup>10</sup> Demand per person is then multiplied by the population of the United States in order to determine the total demand for the domestic airline industry.

Prices are modeled with a hill-climbing formulation that is common in system dynamics modeling (Sterman 2000). Current ticket prices adjust with a delay to the indicated ticket price, which is a function of the margin, costs and the load factor of the industry. Margin pressure is formed from current operating margin normalized by an empirically estimated “target margin.”<sup>11</sup> Cost pressures are calculated as the ratio of the current price per seat mile to the current cost per seat mile adjusted upward by a constant “target percentage above costs.”<sup>12</sup> Ancillary fees have become a much larger share of airline revenues (and costs) in the past decade, and so the cost per seat mile is adjusted downward by the historical ancillary fees per available seat mile, these fees are already included in the data for total costs, and so the net effect on ticket prices from this adjustment is zero.<sup>13</sup>

Similar to the congestion calculation, load factor pressure is the current load factor normalized by the best fit line for the load factor historically experienced by the industry. When yield management technology was introduced to the airline industry in 1985 ticket prices became much more responsive to load factors compared with the period prior. In order to reflect this, the sensitivity of prices to the demand-supply balance is increased after 1985 by a step function with an empirically estimated height.

These effects combine multiplicatively to indicate a percentage adjustment to ticket prices. Their relative strengths are determined by power functions with separate, calibrated exponents.

Costs arise from several sources. Fuel prices are exogenous, as is the time series for the average fuel efficiency of planes. Other variable costs are modeled as a constant dollar amount per seat mile that grows at the rate indicated by the Producer Price

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<sup>7</sup>Estimated by the model parametrization process.

<sup>8</sup>Prices are normalized by the initial ticket price scaled by the CPI, to reflect the increasing affordability of air travel to the general public relative to other goods.

<sup>9</sup>The effect of capacity changes on demand represents the fact that new routes and more accommodating schedules will tend to create their own demand.

<sup>10</sup>The linear approximation fits well over the period from 1970 to 2010, with an R2 of 87%. The estimate is highly statistically significant at the < 1% level.

<sup>11</sup>Pressure from Margin =  $(1 + \text{Target Margin}) / (1 + \text{Current Margin})$

<sup>12</sup>Pressure from Cost =  $\text{Cost} * (1 + \text{Target Markup}) / \text{Price}$

<sup>13</sup>The net effect on the model is not zero however, since the “historical” costs time series is increased by the indicated fees. (Passenger Revenue + Ancillary Fees - Profit = Total Costs)

Index.<sup>14</sup> These normal variable costs are then adjusted by the effect of congestion, since large load factors add costs from increased services, cancellations, and many other sources.

The final component of costs in the model comes from wages, which are endogenously set based on several pressures. I employ a formulation similar to the one used for price, but with five effects determining the indicated wage: inflation, industry margin, national unemployment, average worker tenure and outside opportunities proxied for by the national average wage. The formulation is set so that if there were no net effect from these pressures the average wage for the industry would increase by the percentage change in the CPI each year.

Industry profitability is perceived with a delay by the unions that influence wage negotiations. Profit pushes wages up when airlines are profitable and down when they are not. Economy wide unemployment is normalized by the “normal unemployment rate” set equal to 5%. The outside opportunities of industry workers are represented as the average industry wage normalized by the national average wage. Since there is a skill premium offered for jobs in this industry, average airline wages will be higher than the national mean. The model adjusts the national average wage up by an empirically estimated percentage in order to represent this premium.

The effect of worker tenure on wages comes from the fact that, on balance, rookies will be cheaper to employ than workers with experience. I use exogenous data on average worker productivity to calculate the number of employees in the industry, and use an aging chain with a non-conserved co-flow of worker tenure that accounts in order to arrive at a rough estimate for the average industry experience of an employee over time.<sup>15</sup> This variable then influences the average wage by putting pressure on wages when the average tenure differs from a normalizing constant. The aging chain and co-flow are shown in the figure 2-3.

In order to interpret the fit of the model to historical data the model includes the summary statistics created by Sterman (1984) with a few minor modifications. The mean square error is decomposed into its three Theil statistics, and the square of the error between the simulated and historical data is normalized by the mean of the historical data in order to fit the model along multiple dimensions without over-weighting errors in variables with higher means.

### 2.5.1 September 11th Effect

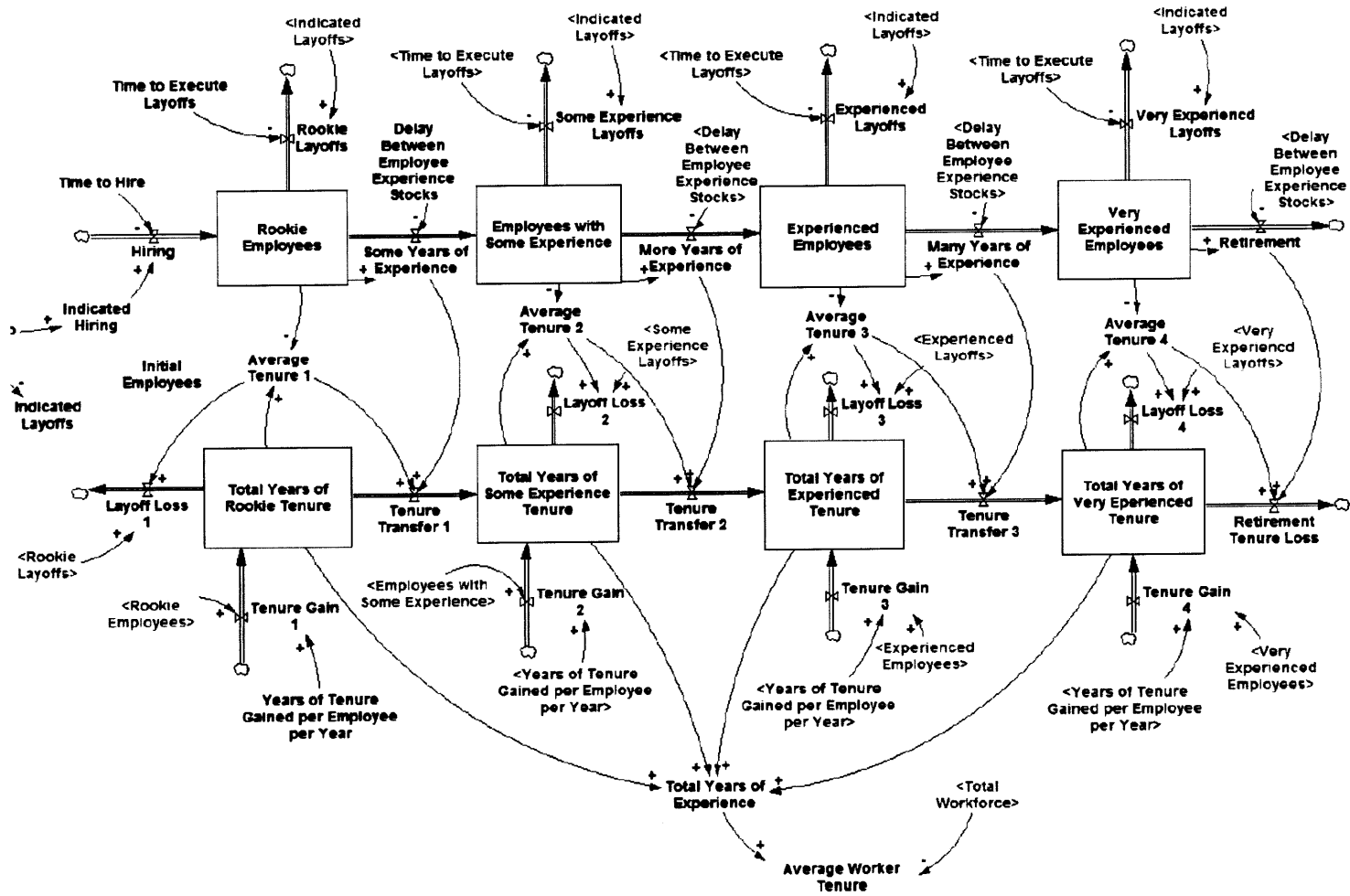
The historical path for airline demand shows a sudden drop from 2001 to 2002, and so the model includes an exogenous shock to demand at the end of 2001. This shock takes the form of a multiplier to the demand for seat miles per capita that increases over a period of time and then decays as the public becomes less influenced by the memory of this tragic event. The two time delays as well as the size of the shock are empirically estimated.

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<sup>14</sup>The PPI excluding food and energy is used to avoid double-counting of jet fuel in the calculations

<sup>15</sup>I model very simple layoffs that remove employees at an equal rate from each stock in the aging chain.

Figure 2-3: Aging Chain and Co-Flow for Worker Tenure Calculations



## 2.5.2 Data Reporting Macro

One of the challenges when fitting models to reported data is that reported data is coarse and discrete, while good system dynamics models output discrete time series with much smaller time steps in order to avoid integration error. Directly comparing reported data with the model's computed values can therefore be difficult because the instantaneous value simulated at any particular time step cannot be viewed as conceptually the same as the value of the reported variable. As an extreme example imagine a model that reported demand for widgets as exactly equal to the historical data on whole numbered years, but zero at all other times. Such a model would fit the data very well, but would not accurately represent the system.

In this essay I document a Vensim macro that efficiently replicates the data reporting process for an arbitrary data reporting period. Using this structure transforms the variables simulated by the model so that variables that are conceptually equivalent to the reported data are available for calibration. This structure and the motivation for using it are not novel in the literature, however no published work to date includes a portable structure that easily adjusts to reporting periods of different lengths. Figure 2-4 shows this structure.

The reporting process records the variable of interest continuously, filling a stock that is waiting to be reported. The stock measures what the reported variable would be if it were to be published during that time step. Once the reporting period has passed the stock is drained at a rate that will empty it in one time step. The reported variable is this rate adjusted for the size of the time step. Since most reported variables are annualized, the reporting structure annualizes the reported variable by dividing by the length of the actual reporting period. Equations for this structure can be found in appendix A.<sup>16</sup>

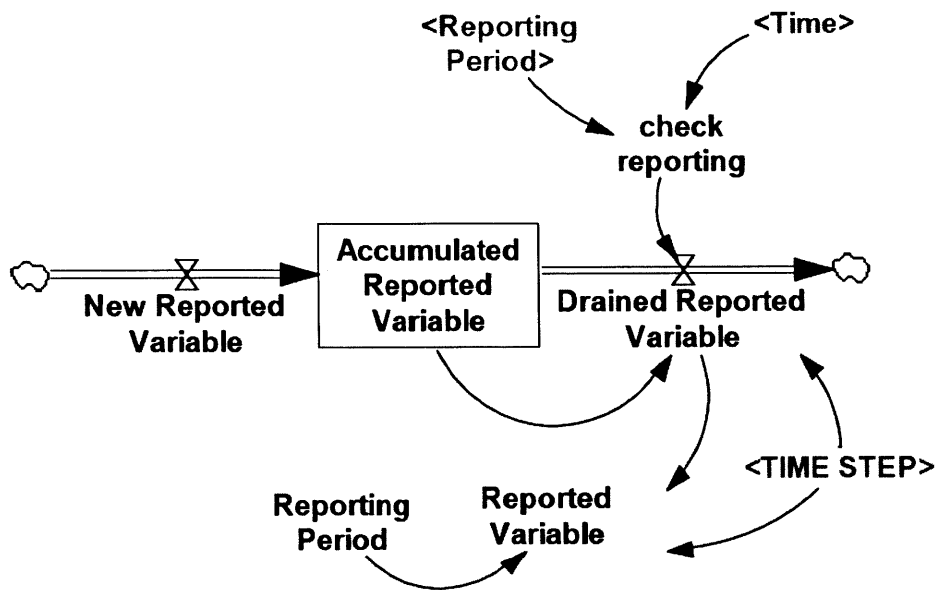
## 2.6 Model Validation

### 2.6.1 Tests of Fit when Driven by Historical Variables

When the feedback loops between major sectors of the model are cut and each portion is driven by the historical data all of the variables except price closely mimic their behavior in the fully endogenous model calibration. Historically, the yield per revenue seat mile has remained remarkably low during this decade, and while I have incorporated the historical effect of transportation related revenue and ancillary fees, cutting the feedback loops between price and the model makes it impossible to find a combination of parameters that can reproduce both the pattern of prices from 1977 until 2001 and the pattern afterward. In the fully endogenous model price has an important effect on many of the other sectors, and so small deviations from its historical path quickly initiate compensating feedback loops that bring price back to the path observed. When those feedback loops no longer work, pressure on price from the

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<sup>16</sup>Please contact the authors for a copy of the model, or a copy of the macro that can be easily implemented in other models



**Figure 2-4:** Data Reporting Structure

rising costs and load factors this decade cannot be accommodated without sacrificing a good fit for the path of prices before the year 2000. This is a potential area for model improvement, though the payoff for a reformulation of the pricing sector in my model is small, because it behaves well when all feedback loops are enabled, and the more standard formulation I use has ancillary, face-validity benefits.

## 2.6.2 Growth Adjusted Capacity Control

The structure used to represent the capital stock of the airline industry is based on the standard stock management structure, but has been modified in several ways. The most significant of these modifications is an adjustment for growth that insures that capacity acquisition decisions do not exhibit steady state error under a constant growth path. Having no steady state error is defined as having a level that will be equal to the desired level when given a consistently patterned goal over a long time horizon. Zero steady state error during growth is important when modeling decisions in an economic context. Even though decision makers have bounded rationality, a constant growth path will not be underestimated over the long run by an actor with an incentive to estimate it well. In this subsection I provide a mathematically rigorous argument for the behavior of my modified structure under a growth path. I assume that the material delays in the stocks are first order as a simplification.

The stock of capacity will equal the desired capacity in the steady state if the inflow of airplane completion equals the retirement of capacity plus the increase in capacity needed to accommodate growth. In the steady state the desired growth rate

of the industry is equal to the actual growth rate. Since zero steady state error means that capacity will be equal to desired capacity, the adjustment for capacity will equal zero in equilibrium. This makes the desired capacity acquisition rate equal to:

$$R + C \cdot g \quad (2.1)$$

Where  $R$  is the level of replacement orders that compensate for capacity retirements,  $C$  is the level of current capacity and  $g$  is the growth rate of demand. By a similar argument, the adjustment for the supply line will equal zero in the steady state and orders for capacity will be:

$$R + C \cdot g + SL \cdot g \quad (2.2)$$

Where  $SL$  is the current level of the supply line of capacity. The model therefore includes terms that adjust orders in the way indicated by equation 2.2. To see why this adjustment ensures that steady state error under a constant growth path will be zero we start by noting that zero steady state error under growth implies that:

$$\lim_{t \rightarrow \infty} C(t) = C_0 e^{gt} \quad (2.3)$$

Where  $C_0$  is the initial capacity and  $t$  is time. Since a good approximation of  $C(t)$  for small time steps is capacity completion minus capacity retirements plus previous capacity,  $C(t-1)$ , it follows that:

$$C(t) - C(t-1) = C_0 e^{gt} - C_0 e^{g(t-1)} = C_0 e^{gt} \cdot (1 - e^{-g}) \quad (2.4)$$

Assuming that  $g$  is small and applying the first term of the Taylor series expansion to replace  $e^{-g}$  with  $(1 - g)$  equation 2.4 becomes:

$$C_0 e^{gt} \cdot (1 - 1 + g) = g \cdot C(t) \quad (2.5)$$

Therefore by the equation for the stock of capacity and by the fact that modeled retirements are equal to capacity divided by the average life of capacity when the material delays are first order:

$$Comp(t) = g \cdot C(t) + \frac{C(t)}{\tau_L} = C(t) \cdot \left( g + \frac{1}{\tau_L} \right) = \frac{1}{\tau_M} \cdot S(t) \quad (2.6)$$

Where  $Comp(t)$  is the capacity completion flow,  $\tau_L$  is the average life of capital,  $\tau_M$  is the delay in manufacturing capacity and  $S(t)$  is the level of the supply line of capacity. By rearranging the final two expressions in equation 2.6 we can rewrite the level of the supply line of capacity as:

$$S(t) = C(t) \cdot \tau_M \left( g + \frac{1}{\tau_L} \right) \quad (2.7)$$

Again assuming a small time step and approximating  $S(t)$  as orders for capacity minus capacity completion plus  $S(t-1)$ , we can incorporate the equivalent expression for  $Comp(t)$  from equation 2.6 to yield:



$$Order(t) = C(t) \cdot \tau_M \left( g + \frac{1}{\tau_L} \right) + C(t) \cdot \left( g + \frac{1}{\tau_L} \right) - S(t-1) \quad (2.8)$$

$$= C(t) \cdot \left( g + \frac{1}{\tau_L} \right) (\tau_M + 1) - S(t-1) \quad (2.9)$$

$$= g \cdot C(t) + \frac{1}{\tau_L} \cdot C(t) + C(t) \cdot \tau_M \left( g + \frac{1}{\tau_L} \right) - S(t-1) \quad (2.10)$$

Combining the results of equations 2.8-2.10 with equation 2.7, equation 2.5 and the definition of a first order material delay gives:

$$Order(t) = g \cdot C(t) + g \cdot S(t) + R(t) \quad (2.11)$$

Where  $R(t)$  is the current rate of capacity retirement, and is equivalent to  $R$  in equation 2.2. Equation 2.11 shows that if the stock of capacity and the capacity supply line are each first order material delays, then their controlling feedback loops will avoid steady state error under growth if the normal order rate for new capacity is added with the growth rate times the sum of both capacity and capacity on order.<sup>17</sup>

## 2.7 Parameter Estimation

### 2.7.1 Approach to Fitting

The parameter space for a large scale model being fit over multiple dimensions is so large that modern desktop computers and automated model fitting algorithms can have difficulty finding global optimums. In order to simplify the task of fitting the entire model to the data I proceeded sequentially, isolating each portion of the model and finding the best parameter set when that portion was driven exogenously by the historical data. I then added the model sections together sequentially, using the first set of parameters as an anchor for each subsequent parameter search. By identifying which sections of the model were highly interrelated and grouping them together during this procedure I was able to do a much more extensive search through the parameter space than I would have been able to accomplish by only performing one calibration with the fully endogenous model. The final parameters estimated are reported in the table 2.1. The 95% confidence intervals reported in the table were evaluated using the non-parametric bootstrapping procedure outlined by Dogan (2007), with a total sample size of 1000 observations.

### 2.7.2 Numerical Issues and Fixes

I estimate the model parameters by seeking to minimize the sum of the square error between the historical data and the model's simulated output. When more than one historical variable is being used to evaluate fit, the error is scaled by the variance

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<sup>17</sup> $R(t)$ , or retirements of capacity are a component of the order rate in the standard stock management structure.

Parameter Name	Lower Bound	Estimated Value	Upper Bound
<b>View: Demand</b>			
Miles per Person per Dollar of GDP ( $\text{seat-miles}/(\text{year}\cdot\$)$ )	0.082	0.093	0.101
World Miles per Person per Dollar of GDP ( $\text{seat-miles}/(\text{year}\cdot\$)$ )	0.047	0.05	0.059
Sensitivity of Demand to Congestion ( $dmnl$ )	-0.94	-0.726	-0.53
Congestion Perception Time ( <i>Years</i> )	0.43	0.75	1.12
Strength of New Capacity Effect on Demand ( $dmnl$ )	0	0.25	0.69
Strength of Affordability Effect on Demand ( $dmnl$ )	0	0.106	0.257
Constant Demand Adjustment ( $\text{Seat-miles}/\text{person}\cdot\text{year}$ )	-1152	-1087.7	-940
Length of 9/11 Effect ( <i>Years</i> )	0.479	0.5	0.969
Size of 9/11 Effect ( $dmnl$ )	0.113	0.185	0.32
Public Perception of Terrorism Decay Time ( <i>Years</i> )	2.38	4.25	7.13
<b>View: Capacity</b>			
Time to Adjust Capacity ( <i>Years</i> )	0.226	0.594	0.75
Supply Line Adjustment Time ( <i>Years</i> )	0.05	0.1	0.62
Time to Perceive Changes in Demand ( <i>Years</i> )	0.05	0.125	0.381
Time to Perceive Trend in Demand ( <i>Years</i> )	0.2	0.3	0.5
<b>Wages</b>			
Time to Change Worker Compensation ( <i>Years</i> )	0.43	1	1.53
Strength of Margin on Worker Compensation ( $dmnl$ )	0.25	0.425	0.71
Normal Margin ( $dmnl$ )	0.039	0.068	0.09
Margin Perception Delay ( <i>Years</i> )	0.5	1	1.8
Normal Unemployment ( $dmnl$ )	0.02	0.048	0.06
Normal Worker Tenure ( <i>Years</i> )	11.79	14	14.69
Strength of Outside Opportunities on Compensation ( $dmnl$ )	0.65	0.75	0.9
Strength of Tenure Effect on Wages ( $dmnl$ )	0.3	0.425	0.6
Strength of Unemployment Effect on Wages ( $dmnl$ )	8.1	10	22.3
Wage Premium for Skill ( $dmnl$ )	1.172	1.2	1.56
<b>Price</b>			
Original Sensitivity of Price to Demand Supply Balance ( $dmnl$ )	0	0.25	0.92
Effect of Yield Management on Sensitivity ( $dmnl$ )	1.75	2.25	2.89
Sensitivity of Price to Costs ( $dmnl$ )	0.1	0.3	0.438
Sensitivity of Price to Margin ( $dmnl$ )	0.139	0.4	0.82
Target Margin ( $dmnl$ )	0.042	0.05	0.1
Target Percentage Above Cost ( $dmnl$ )	0.54	0.54	0.586
Time to Adjust Ticket Prices ( <i>Years</i> )	0.04	0.05	0.26
<b>View: Costs</b>			
1977 Other Variable Costs( $\text{dollars}/(\text{seat}\cdot\text{mile})$ )	0.02449	0.0245	0.02495

**Table 2.1:** A list of the constants estimated by the model fitting procedure is shown in this table, with units indicated in parentheses to the right of the variable names and bootstrapped 95% confidence intervals recorded as lower and upper bounds. *Dmnl* stands for dimensionless, and includes fractions, ratios and percentages along with constants used as the exponents of power functions. The nonparametric bootstrap with the percentile method put forward by Dogan (2007) was used for the calculation with a total sample size of 1000 observations.

of each historical variable. This structure closely matches the methodology of least squares estimation while avoiding one potential pitfall. By scaling with a constant that is likely to be proportional to the variance of the estimation error, I avoid over-weighting errors in variables with higher means when optimizing over more than one dimension.

If the error were measured at each time step, the estimation procedure would be weakened because only a small percentage of the time steps simulated correspond to actual data points in the historical series. Therefore, the “pick” function in the summary statistics module is utilized to ensure that the error is measured only when appropriate.<sup>18</sup>

The well-known “endpoint” problem in model calibration arises when reported data for a particular year does not match correctly with the time step it is compared against. For instance, reported airline demand for 1977 is the sum of the demand each day during 1977 and is not reported until 1978. Since the model simulates this summation process and also outputs the result at the beginning of 1978 I have modified each of the table functions representing the historical time series so that their data for a given year will be displayed during first time step of the following year. Specifically, when the model computes variables such as the average ticket price over the year 1995 and reports that value at the beginning of 1996, I match this to the historical 1995 average ticket price by calling a table function that contains the historical data with the input  $(Time - 1)$  rather than simply  $(Time)$ .<sup>19</sup>

## 2.8 Evaluation of Fit

### 2.8.1 Summary Table

The overall fit of the model has relatively high  $R^2$ , low error as a percentage of the mean, and Theil U statistics that indicate that the error tends not to come from differences in the means of the variables. For all of the variables other than cost the Theil statistics also indicate that the error is due mostly to random variations in the historical time series. The formulation for cost in the model is very simplistic, with jet fuel costs and wage costs being driven entirely by other sectors in the model. The only other variable controlling the fit of costs is modeled as a constant multiplier of the producer price index. When this is considered alongside the relatively small size of the total error for costs this limitation of my model fit should not detract markedly from the overall results.

In the following subsections I discuss the goodness of fit of each of the model’s variables, grouping them into pairs that are closely interrelated. While the summary table in the above figure is meant to be a quantitative treatment of the fit of the model I intend the rest of this discussion to be more qualitative, discussing fit within the context of the history of the industry and the reasonableness of the estimated

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<sup>18</sup>Sterman 2000, *Business Dynamics*, contains the summary statistics module I mention in its electronic supplement.

<sup>19</sup>Use  $Table(time - 0.25)$  for quarterly reporting.

Variable	$R^2$	$MAE$	$RMSE$	$U_m$	$U_s$	$U_c$
<i>Capacity</i>	97.88%	3.79%	4.48%	0.90%	2.25%	96.84%
<i>Demand</i>	99.52%	2.16%	2.77%	3.60%	12.36%	84.04%
<i>Wages</i>	40.05%	3.88%	5.00%	2.46%	11.07%	86.46%
<i>Cost</i>	99.57%	3.26%	4.18%	3.18%	45.42%	51.40%
<i>Prices</i>	79.47%	4.82%	6.09%	2.46%	9.84%	83.33%
<i>Profit</i>	57.71%	170.7%	240.3%	7.66%	12.37%	79.97%

**Table 2.2:** The statistics in this table show the goodness of fit of the simulation to the historical data during the period from 1977 through 2010.  $R^2$  is the coefficient of determination, defined as one minus the ratio of the sum of the squared error to the total sum of the squares.  $R^2$  is not a good indicator of fit for growing data series.  $MAE$  is the mean absolute error divided by the mean of the data.  $RMSE$  is the root mean square error divided by the mean of the data. These statistics are a better measure of fit for growing data series.  $U_m$ ,  $U_s$ , and  $U_c$  are the Theil statistics, and correspond to an estimate of the portion of the estimation error that comes from a difference in means, a difference in variance and a difference in covariance (random fluctuations), respectively.

parameters.

## 2.8.2 Demand and Capacity

There are feedbacks to demand from both capacity and prices, and so I've chosen to discuss capacity and demand together, leaving prices for treatment later because price is the most centralized variable in the model. Overall the parameters estimated for demand and capacity are reasonable. The fact that the supply line adjustment time is smaller than the capacity adjustment time conforms with the finding from Forrester and Senge (1980) that supply line adjustment tends to be more reactive than stock adjustment.

The parameters surrounding the forecast of demand are all within the ranges that would be expected. The parameters estimated for demand also have high face-validity. The number of miles per capita demanded for each dollar of world GDP is lower than the miles demanded per dollar of domestic GDP, because even though international flights are physically longer many fewer flights are demanded per-capita. New capacity increases demand by a small amount, and demand is sensitive to congestion when congestion is persistent.

The model structure that was added to represent the exogenous effect of the September 11<sup>th</sup> attacks on airline demand generated parameters during model calibration, that are similar to those estimated in the economic literature surrounding the effect those attacks had on the demand for air travel. For instance, Ito and Lee (2005) estimate that the attacks resulted in a drop in air traffic demand of as much as 30% at their peak, and that the majority of the reduction had not dissipated by the end of 2003. While my structure does not hit those estimates exactly it does conform with the qualitative nature of their results, as I find a 20% instantaneous reduction

## Historical and Simulated Revenue Passenger Miles

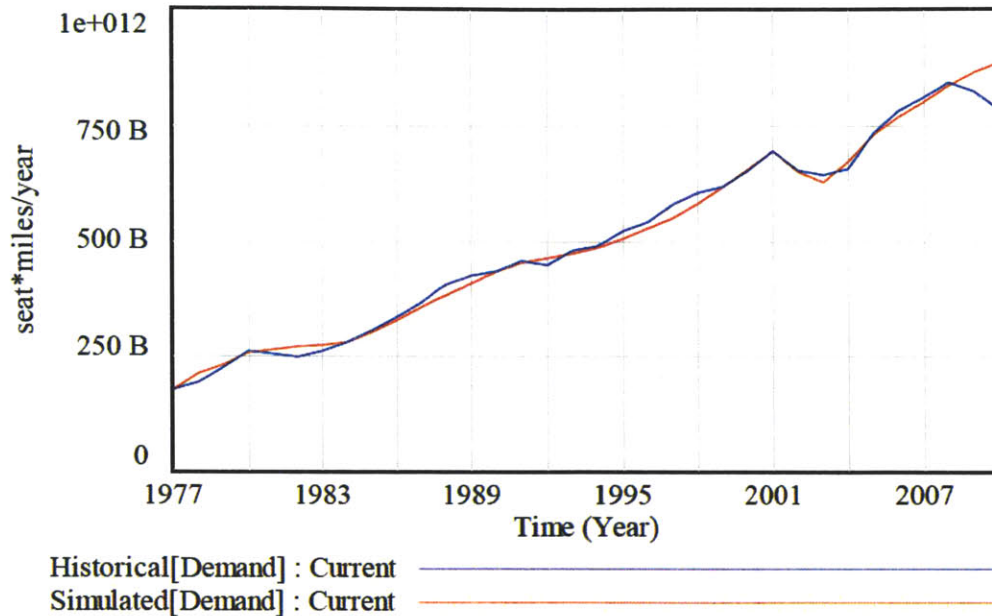


Figure 2-5: Historical and Simulated Demand

that dissipated over many years<sup>20</sup>.

The overall fit of capacity shows a similar pattern to that of demand, with a significant divergence from the historical path in 1983, and another after the 1992 gulf war. This should be expected given the model structure, because the largest determinant of the industry's capacity is the level of demand forecasted. After 9/11 however the model does not anticipate the degree to which the industry is reluctant to increase capacity in the face of growing costs. This may be because the model structure does not incorporate some new dynamic emerging in the industry, suggesting the potential for improvement of the causal structure of the model by future model consumers. Another explanation for this mismatch may lie in the linear relationship between GDP and indicated demand modeled, since over time the portion of the gross domestic product that generates demand for air travel has changed with the advent of high speed communications. Extensions of my work should look to improve on our understanding of demand and capacity in the airline industry, potentially by specifying the dependence of airline demand on each component of GDP rather than using the simple structure I employ.

<sup>20</sup>There are many reasons for why my model estimates the shock differently. For instance, the endogenous feedback between capacity and demand is excluded from econometric models of airline demand. Since airline capacity was cut after September 11 some of the reduction in demand in my model is causally related to that change, and so my estimate of the 9/11 demand shock is smaller.

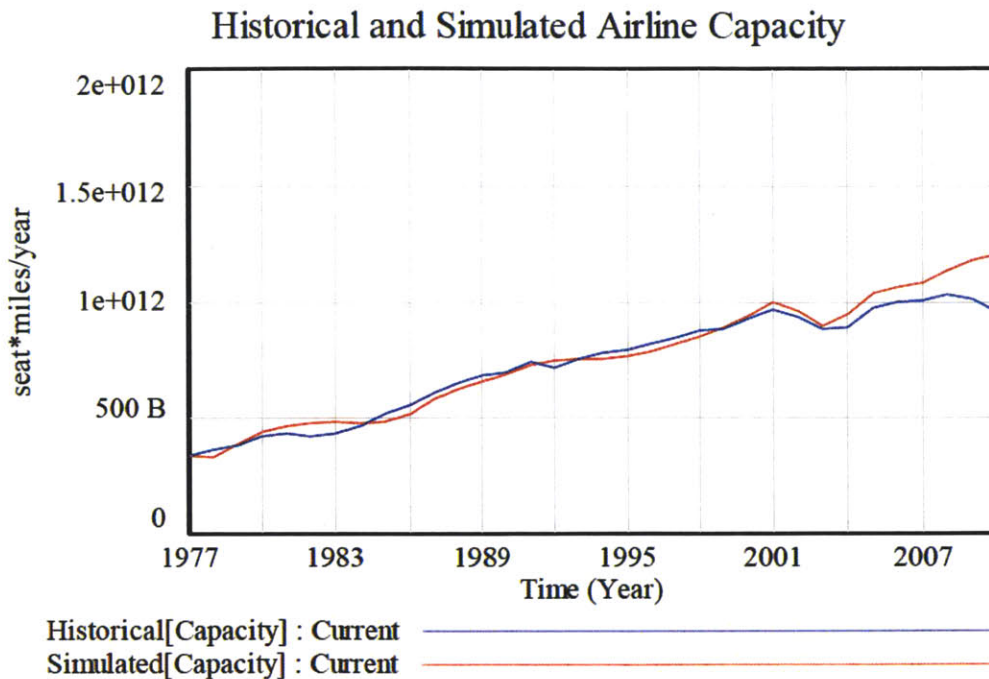
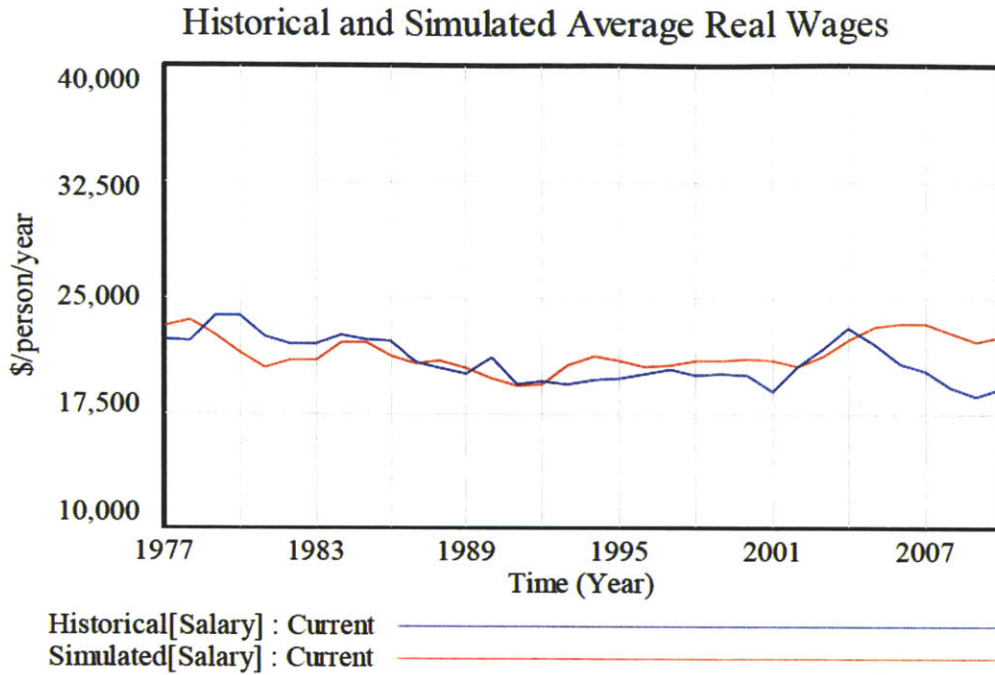


Figure 2-6: Historical and Simulated Capacity

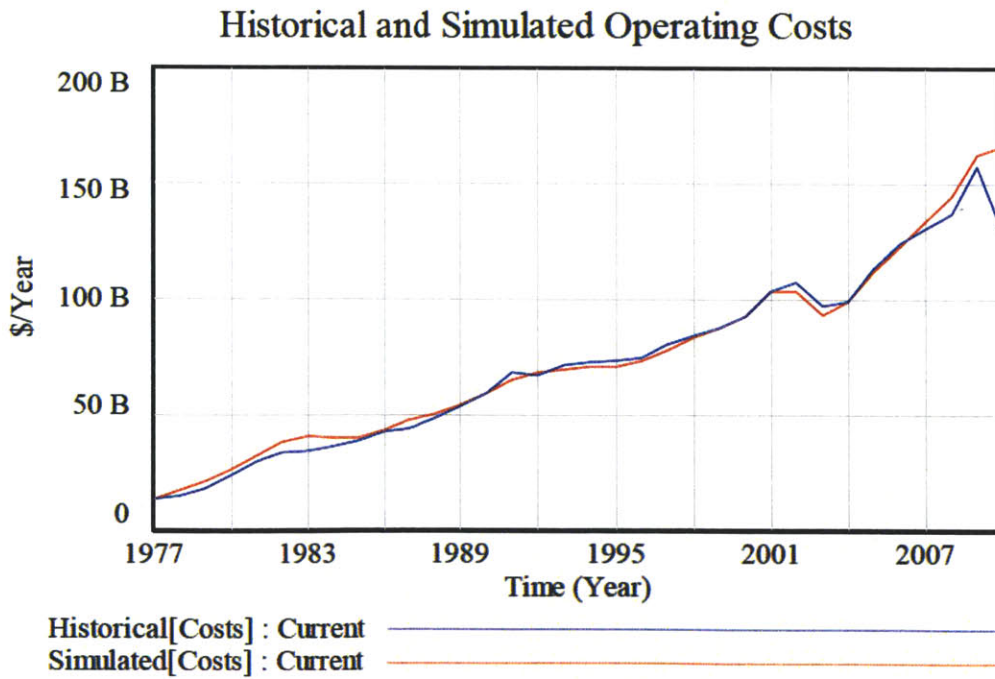
### 2.8.3 Wages and Costs

While airline capacity is an important determinant of overall costs in the industry, the variability in that relationship is largely controlled by the effect of jet fuel prices and the endogenous wage setting structure. The fit for simulated wages, shown in figure nine as CPI deflated real wages, is very close to the historical average real wage in the industry, although the model again has difficulty fitting the most recent data. The low inflation during this period may have stressed the model's assumption that wages in the industry will increase at the rate of inflation in equilibrium, causing the fitting algorithm to compensate by overestimating the upward pressure on wages from other sources. Overall however the 40%  $R^2$  for the fit on real wages, when considering the fact that the model uses the nominal value of wages in its calculations, stands.

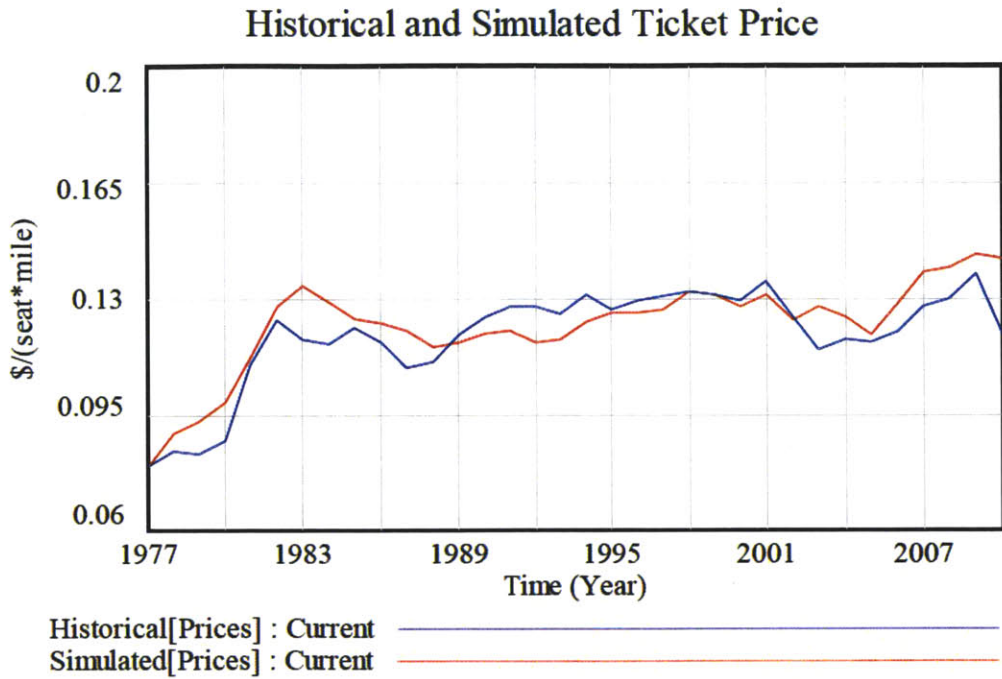
The parameters estimated indicate that margin is a surprisingly small determinant of airline industry wages. Unemployment in the overall economy and outside opportunities have a much larger effect on average wages in the simulated industry. While the size of the parameter for controlling the strength of the tenure effect on wages is small, the fact that the average worker tenure has the largest range of any of the time series that influencing average wages means that the effect of a workforce tenure is still very important.



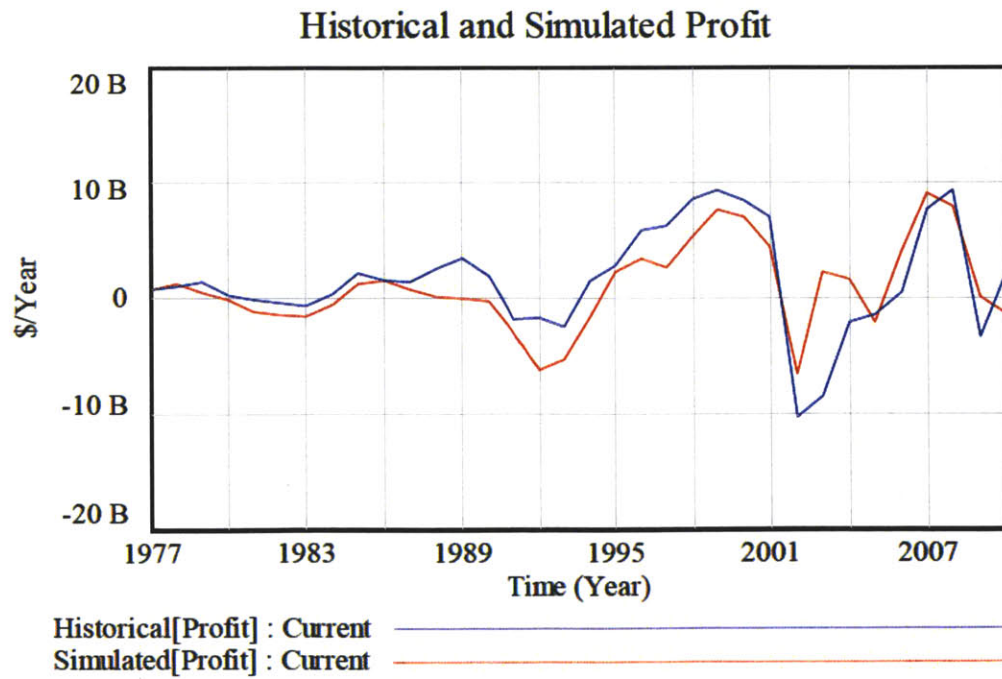
**Figure 2-7:** Historical and Simulated Real Wages



**Figure 2-8:** Historical and Simulated Operating Costs



**Figure 2-9:** Historical and Simulated Ticket Prices



**Figure 2-10:** Historical and Simulated Operating Profit



## 2.8.4 Prices and Profit

Price is by far the most centrally connected of the stocks I model. It has a direct effect on demand, it affects each of the other sectors through its effect on profit, and many of the other sectors of the model feed-back to directly affect it. This observation informs the results of the model for fitting ticket price because the structure of the model forces price to fit well in order for the other sectors of the model to fit well. The model parameters lend anecdotal support to this formulation because they indicate that after the introduction of yield management, load factors were the single most important determination of ticket price. This corresponds well with intuition obtained from talking with sources in the industry.

The fit of the model to historical operating profit is, perhaps, the most critical of the model's results. Even though the determinants of revenue and costs had some systematic errors in their fit to the data, the difference of these two large numbers produced a simulated path for profits that exhibits the majority of its error from random covariation between the historical data and my simulation.

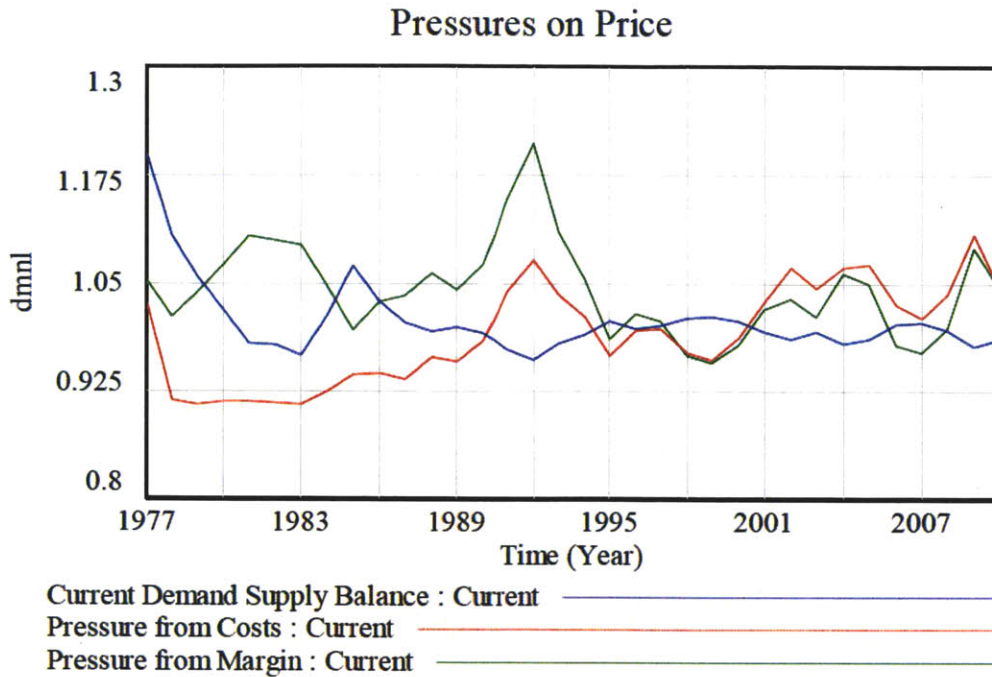
## 2.9 Policy Recommendations

### 2.9.1 Description of the Cycle in Profits for Airlines

Most system dynamics models of business cycles suggest policies that control capacity, since this balancing loop is the underlying cause of the cycle. One of the advantages of this model's broad boundary however, is its ability to test policies unrelated to capacity control. One insight that arose from my parametrization of the model was the centrality of ticket price within the overall model. An examination of the time path of the pressures on profits reveals an interesting pattern of covariance between the three sources of pressure on ticket prices.

Figure 2-11 plots the pressure on price from costs, the pressure on price from margin, and the pressure on price from the demand supply balance before any of those pressures are adjusted by their respective sensitivities. It is clear from inspection that the pressure on prices from costs and margins have a high correlation, while the pressure on price from load factors varies inversely with the other two. An operational description of this phenomenon follows directly from the mechanics of the airline profit cycle. When profits are low airlines are experiencing insufficient load factors that put downward pressure on prices in order to increase demand, however low profits and high costs send a signal to raise prices. Yield management means that the signal from load factors will feature heavily in pricing decisions, exacerbating the downturn.

That description is not novel, but the interpretation of the dynamic within my model leads to one observation that is interesting: from an industry standpoint demand is fairly price inelastic, and so the decision to compete heavily on price during downturns leads to lower profits for everyone. Essentially, the pressure on prices from load factors is pro-cyclical, while the pressure on prices from costs and margins is counter-cyclical. If yield management is removed from the simulated industry by setting the sensitivity of price to the demand supply balance to zero the cycle in profits



**Figure 2-11:** Size of Unadjusted Pressures on Ticket Prices

still exists, but its amplitude is smaller and its average value is both much higher and mostly positive.

### 2.9.2 Pricing Rules Absent Yield-Management

In order to simplify the interpretation of how the pressures on price combine to exacerbate the airline profit cycle I first test the implications of varying the sensitivity of price to costs and the sensitivity of price to margin while the sensitivity of price to the demand supply balance is set to zero.

Figure 2-13 shows the average profit over the model run from 1977 to 2010 plotted over the parameter space defined by the price sensitivity to costs and the price sensitivity to margins each varied between zero and two. The results, unsurprisingly, show that pricing to maintain high margins will result in high margins. It is interesting to note however that considering costs along with margins during price setting is generally detrimental to overall profits, but the effects do not become pronounced until the sensitivity of price to costs is roughly twice the sensitivity of price to margin.

Figure 2-14 shows the same parameter space, rotated slightly to better show the surface graphed, with the variance of profits is plotted in the place of the average of profits. This analysis shows the effect on the volatility of profits of pricing decision rules. The sensitivity of price to cost is strongly positively related to the variance of profits, suggesting that pricing rules that emphasize reactions to profit rather than

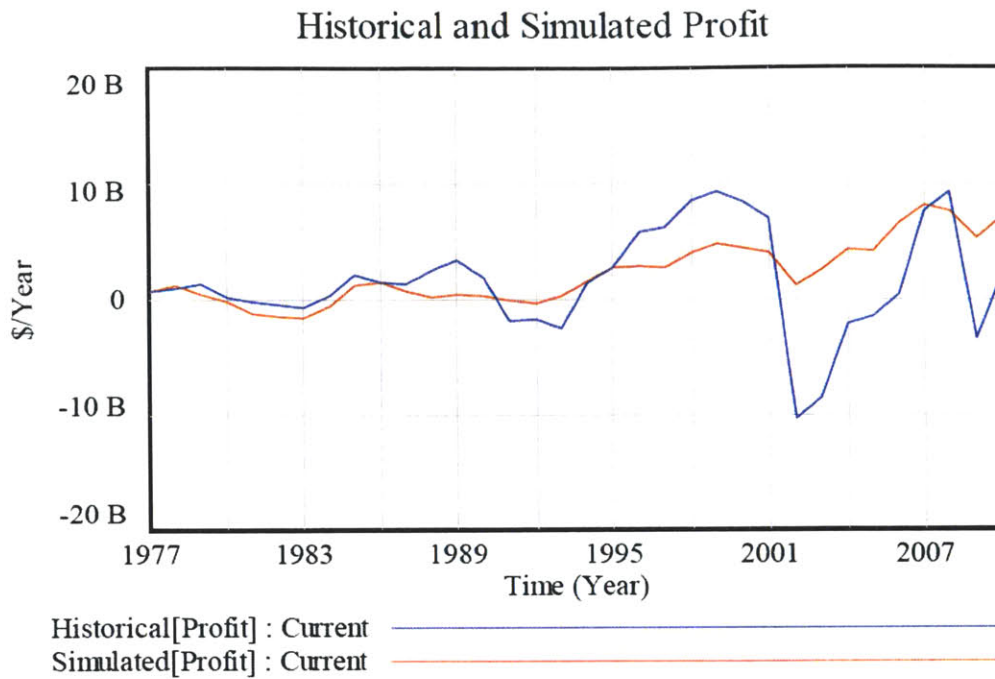


Figure 2-12: Simulated and Historical Profits when Ignoring Load Factor for Pricing

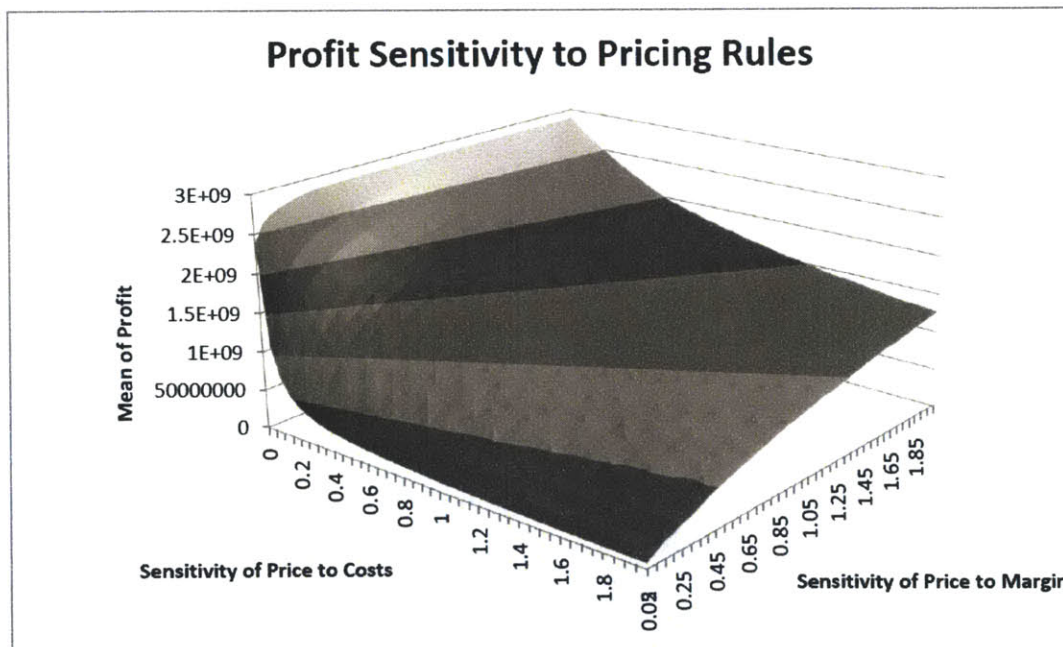
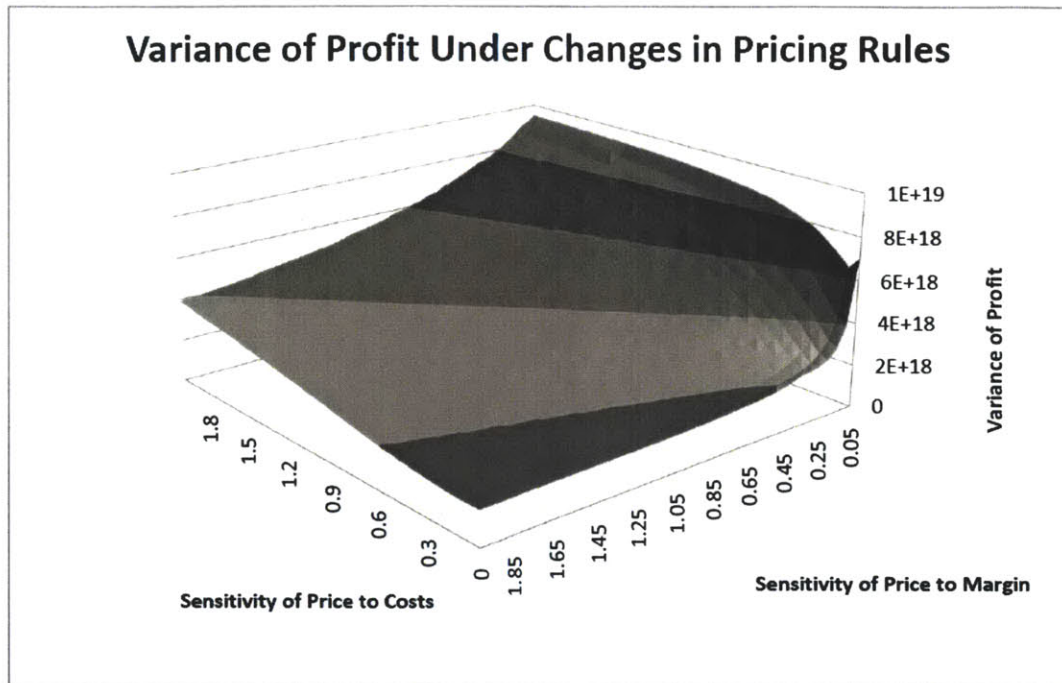


Figure 2-13: Average Profit Under Changes to Pricing Rules with no Yield Management



**Figure 2-14:** Variance of Profit Under Changes to Pricing Rules with no Yield Management

markups reduce the severity of the cycle in profit.<sup>21</sup> Because the global minimum for variance in profit occurs at the same location as the global maximum for the average profit, the corner where margin sensitivity is at its maximum and cost sensitivity is zero, these two tests make a strong, preliminary case for a pricing rule that focuses heavily on maintaining profit over other considerations.

### 2.9.3 Pricing Rules Under the Presence of Yield Management

When the same parameter space of pricing rules is evaluated when including yield management by setting the sensitivity of price to the demand supply balance to 1. The results for the average value of profit at the end of the model run in figure 2-15 show an important result for our understanding of the genesis of, and adherence to yield management in the airline industry.

In figure 2-15, the large spike in average profits occurs at the point where both the sensitivity of price to margin and the sensitivity of price to costs are at their minimum. If the average level of profit is the only metric of interest, then decision makers in the airline industry are well advised to focus singularly on maximizing the load factors their companies experience.

<sup>21</sup>In fact, if this data were analyzed as a vector field the divergence of the variance with respect to the sensitivity of price to costs would be positive at every point except the point where both sensitivities are zero.

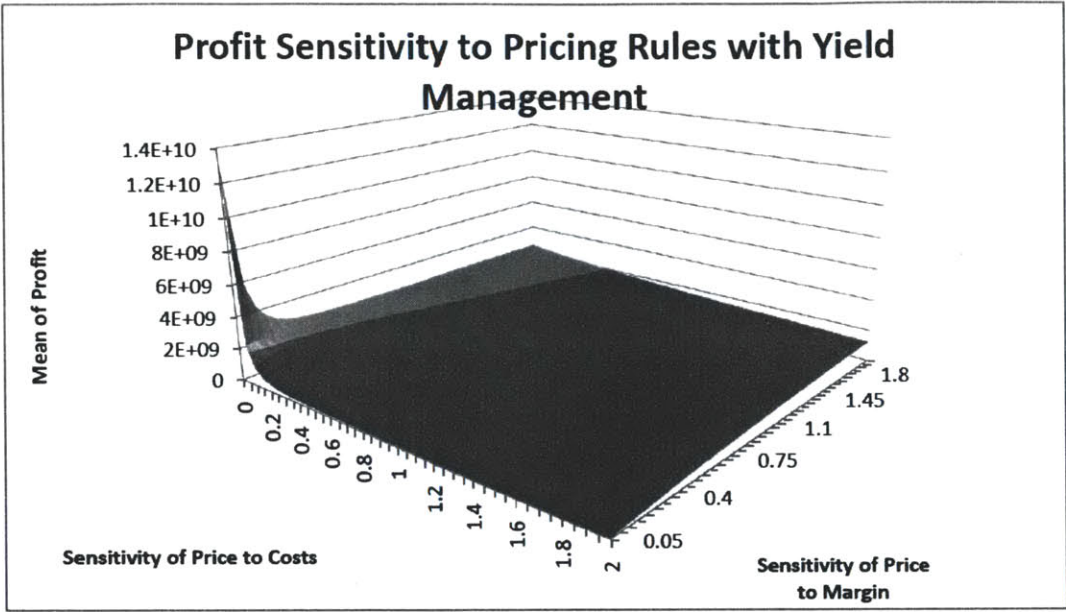


Figure 2-15: Average Profit Under Changes to Pricing Rules with Yield Management

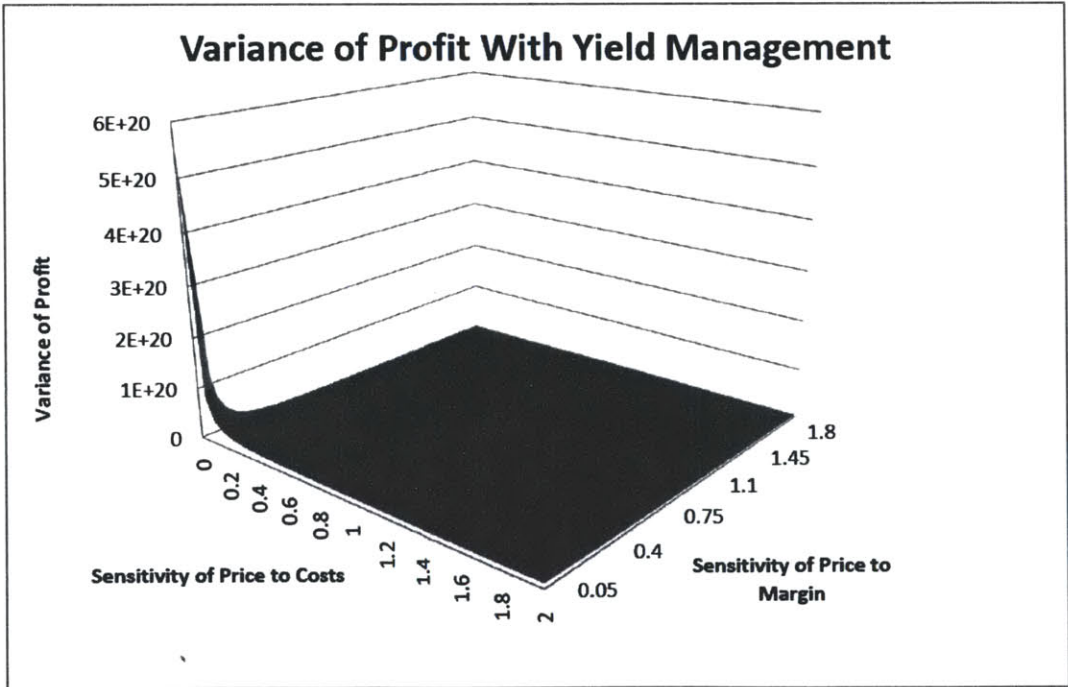
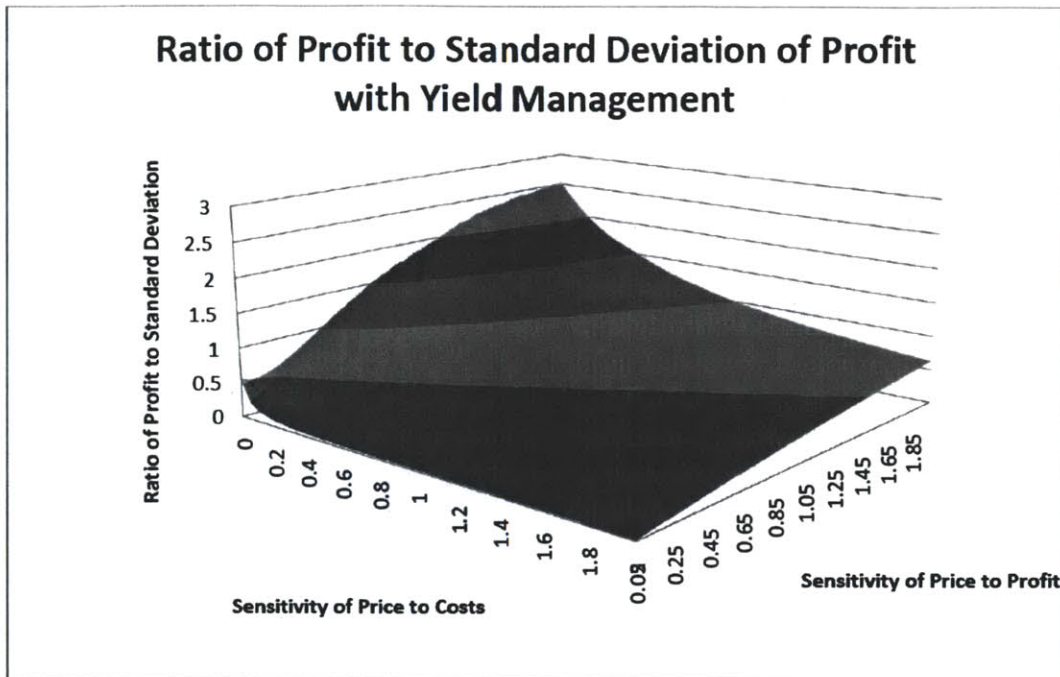


Figure 2-16: Variance of Profit Under Changes to Pricing Rules with Yield Management

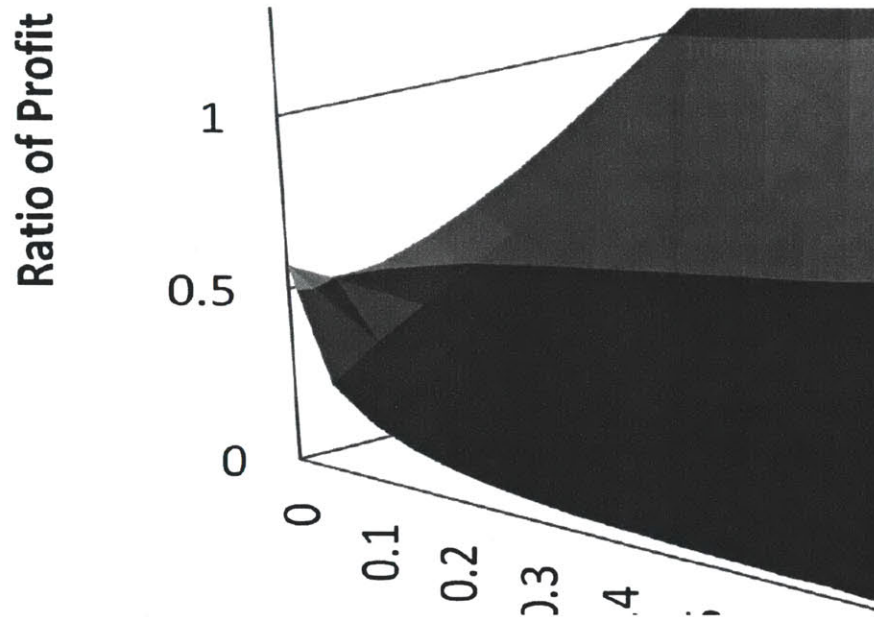


**Figure 2-17:** Variance Scaled Profit Under Changes to Pricing Rules

When we consider the variance of profits as well as their average level however, the picture becomes less clearly positive. Figure 2-16 shows that while the pricing strategy of maximizing profits through high capacity utilization does produce very high profits, it also greatly exacerbates the volatility of those profits. While none of the parameter combinations tested here completely eliminate the cycle in airline industry profits, the set of parameters identified by my model parametrization as the most likely standard in the airline industry, a high sensitivity to load factors and a low sensitivity to other pressures, is also the set of parameters that will maximize the variance of profits.

Of course, data with a higher mean will naturally have a higher variance. In order to test whether the high variability of the simulated profits are simply related to the high mean of those profits or whether pricing policies are increasing the amplitude of the cycle more than would be expected by the increase in its average, figure 2-17 plots the ratio of the average profits at the end of the model run to the standard deviation of those profits. The results are striking on two levels. First, the policy suggested by the analysis with yield management turned off reasserts itself as the best trade-off between the size of profits and the amplitude of the cycle. Second, the current, suboptimal decision rule of maximizing average profits by focusing on maintaining load factors is revealed to be a local maximum of the trade-off between profit and variance in figure 2-18.

The first result lends support to a policy not previously proposed by the system dynamics literature: regardless of the industry’s approach to capacity adjustment, a



**Figure 2-18:** Detail of the Current Local Maximum

pricing policy that accepts some slack capacity, competes very little on markup, and focuses heavily on using ticket prices to ensure that margins are kept at reasonable levels can produce a much smoother path for profits than currently is experienced.

The second result is interesting from a different perspective. The fact that adjusting price primarily through load factor is a locally optimal solution to the problems presented by the airline profit cycle suggests that, at least in the airline industry, decision makers who focused on load factors were boundedly rational in improving the financial performance of their industry. Yet the model suggests, and professionals in the industry might agree, that a myopic focus on momentarily high profit is damaging the industry's ability to stay solvent in the long run, because the policies adopted as the best practices of the industry are unsustainable if they cause profitability crashes.

Within the context of the broader system dynamics literature this result tells a compelling, behavioral story about the evolution of policy resistance and better before worse archetypes from the perspective of an industry focused on profitability. If financial markets are focused on the level of profits with very little attention paid to second order effects then managers in the airline industry are acting rationally. If, on the other hand, publicly traded firms believe that the market values smooth earnings, as suggested by many academics (Burgstahler and Dichev 1997), then air transportation companies may need a deep understanding of their industry dynamics in order to maximize equity valuations. De-emphasizing yield management will greatly reduce the level of profits in the short term, but will have many benefits for the industry in the long run.

## 2.10 Conclusion

While my model supports the well accepted view that a misperception of the delay in adjusting capacity is central to the genesis of profit cycles exhibited by the airline industry, it also presents a case for how feedback rich models enhance our understanding of systems by testing a policy for price setting that greatly reduces the variance of the cycle. The simulations show that pricing policies that focus primarily on achieving high load factors increase profit levels at the expense of profit stability. Simulation tests also provide evidence that yield management is a locally optimal solution to the trade off between profit levels and volatility, even if it is far from the global optimum, and therefore may be difficult to transition away from unless industry professionals can adapt their mental models.

Without the plethora of publicly available data on the airline industry the model documented here would likely not be available for scrutiny and enhancement, which highlights the importance for system dynamics academics of finding settings where similar amounts of data can be obtained. This data also enable the model to have greater face validity with professionals by including many endogenous feedbacks; potentially enabling future work on novel strategies for lessening the severity of profit cycles from inside the industry.

By documenting a model for the airline industry that matches the simulated data with the what has been observed historically this work offers a small step towards a collaborative understanding of the industry, and highlights important aspects of the process of model calibration. The capacity adjustment for growth formulation, shown to eliminate steady state error under growth paths, has potential applicability to many modeling settings. This modification provides additional realism to the standard capacity adjustment structure by ensuring that the simulated decision makers act reasonably when faced with persistent growth.

Looking to the future, the commodity nature of air travel and the rising costs of jet fuel mean that air transportation companies will face pressure from sources other than just the cyclical forcing of aggregate profits. This inquiry into why airline profits cycle is offered in the hope that its insights will be useful as we attempt to stabilize airline industry profits so that airlines can continue providing a vital service to the global economy.



## Chapter 3

# Cycles in Casualty: An Examination of Profit Cycles in the Insurance Industry

### 3.1 Introduction

The property-casualty insurance industry has exhibited cycles in profitability for decades, as shown in figure 3-1. During the 1980's when a cyclical dip in the profitability of insurers threatened their long-term viability, the causes of the insurance cycle were hotly debated among academics and industry professionals. Commonly accepted wisdom within the industry holds that the drops in profitability are caused by unforeseeable major disasters or other exogenous shocks. According to view theory profitability slowly improves after these events pass, because insurers gradually rebuild capital stocks and readjust to the new risk landscape over time.

Academics also have a host of competing theories on the origin of cycles. Regression analysis by Doherty and Kang (1988) has shown significant correlation between macroeconomic variables and insurer profitability, while in contrast numerous econometric models of the price setting and revenue generating process in the industry have suggested that autocorrelation in profits might arise endogenously, as shown by Venezian (1985). Nevertheless, the origin of the cycle, and the extent to which it is endogenous to the industry's structure and decision practices, remains unclear.

In this chapter I build a medium-scale, feedback-rich model of the property casualty insurance industry to explore the relative contribution of macroeconomic variables, exogenous disasters and endogenous feedback to profit cycles. The model incorporates decision making processes for premium setting, loss expectation formation and risk standard setting that are approximate to those used in the industry. When these processes are combined to create a simplified but realistic picture of how the industry operates, the results suggest that profit cycles in the insurance industry can be explained endogenously. The macro-economy and the incidence of accidents, while important for determining profitability, are likely not primary causes of the cycle. In tests where the model is shocked out of dynamic equilibrium the fact that

these exogenous influences are held constant does not eliminate the cycle.

This modeling work offers a novel dynamic hypothesis within the system dynamics literature on cyclicity. Currently the literature points to negative feedback loops around capacity adjustment as the primary cause of profit cycles. In my model I assume that the insurance industry can adjust its productive capacity instantaneously and at no cost.<sup>1</sup> While this structure makes the model less realistic, cutting this feedback loop allows my model analysis to focus on the central hypothesis, that cycles in profitability for the insurance industry are caused by the delay in adjusting the riskiness of and revenue from the book of underwriting business.

Many of the decisions made in an insurance company can be modeled as negative feedback processes that use profitability or capital adequacy as signals to adjust policy levers. Because the effects of these decisions accumulate in a stock of currently underwritten policies, the levers managers are able to use to control profit act only with a delay. My conclusion that profit cycles in the insurance industry arise regardless of the capacity adjustment process is therefore similar to existing work; but, by laying out a new mechanism for profit cycle causation this research suggests a host of applications for similar cyclical models in industries where system dynamics modeling has not previously been applied because capacity adjustment was not likely to be a factor in the cyclical forcing of profits.

For parametrization I collate an aggregate data set of financial variables for the property-casualty insurance industry from Compustat, and use it to calibrate the model to the observed historical behavior.<sup>2</sup> The behavior of the model is also analyzed under the effect of separately calibrated, stochastic patterns for the exogenous inputs. Using these inputs I analyze the correlation between the model variables and a broader range of historical variables available for the entire insurance industry. This process is augmented by an implementation of an ARIMA model driven by a simple Markov process for the standard pink-noise generator.<sup>3</sup>

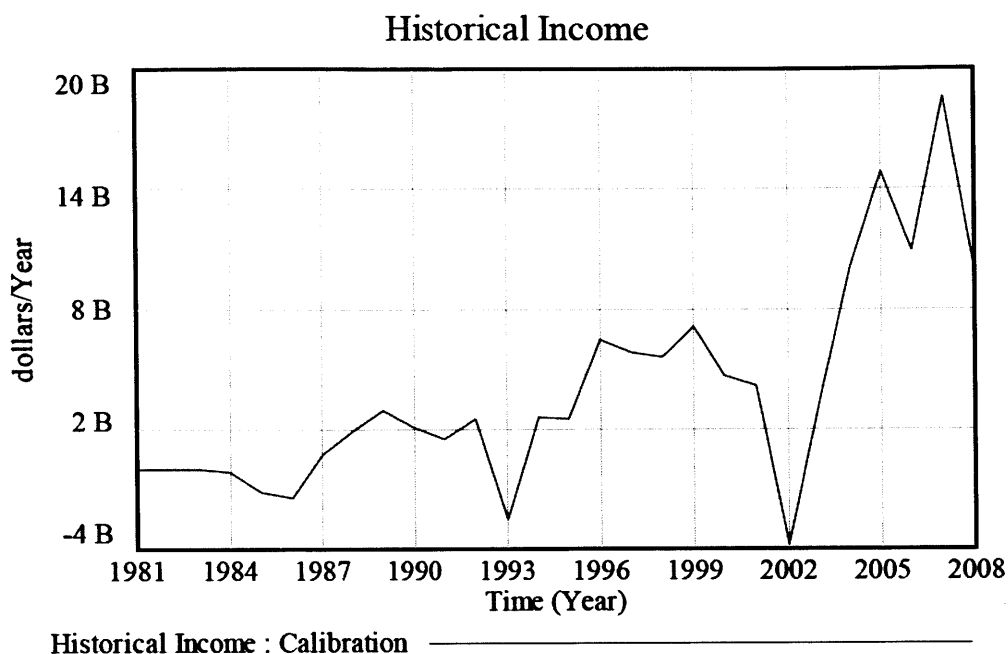
Finally, my analysis suggests an interesting strategy for mitigating the severity of the profit cycle in the insurance industry. In simulation tests the stock of investment capital for the industry is shown to do remarkably little to limit the severity of the cycle when only the target for its level is changed. Actions that ensure high adequacy of capital are only effective when capital is used as the most salient input to decisions effecting the scope of the insurance industry. This result suggests that regulation to ensure higher capital adequacy will only be effective at ensuring high profits in the insurance industry if industry actors are fully committed to using the capital as the most important determinant of their financial health, rather than focusing on recent net income.

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<sup>1</sup>In fact, the productive capacity of the industry is excluded from the model structure as costs from these sources are treated as a constant function of the amount of work that needs to be done.

<sup>2</sup>Specifically, this means premiums collected, claims incurred and operating profit, as these variables are both salient and available in the Compustat data for the segment of the industry I am interested in.

<sup>3</sup>I use normal probability plot analysis of the historical data for investment returns to calibrate the structure, following Webster et al. (2007) in their analysis of refinery emissions in Houston. The pink noise formulation is covered by Sterman (2000).



**Figure 3-1:** Historical Aggregate Net Income of the Property-Casualty Insurance Industry.

## 3.2 Literature Review

Researchers examined the nature and causes of the insurance cycle extensively during the 1980's and the first half of the 1990's. By the end of that period a substantial body of literature had separated into three groups (Gron 1994).

The first body of research hypothesized that the cycle was caused by interest rate fluctuations and exogenous shocks (Doherty and Kang 1988). Later research within this school of thought added additional macroeconomic variables to the regressions for estimating insurer profitability (Grace and Hotchkiss 1995). Even though these tests improved in explanatory power as they developed, they still could not explain the majority of the variation in combined ratios or operating profit, and did not hypothesize causal directions for the statistical relationships they documented.

A second stream of research focused on excessive regulation as the most likely cause of insurance profit cycles. These capacity-constrained models held that rational expectations and competitive markets would overcome the cycle if regulators would stop limiting the supply of insurance by mandating the level of reserves (Winter 1991). These models tended to be very simple in structure, and were criticized for neglecting two important interactions. The first critique was that insurer bankruptcy is also a large supply shock, and deregulation would likely increase the risk of insolvency. The second was that the limited supply of insurance available was not the only problem during the 1980's liability insurance crisis, and the increasing rate of claims by policyholders was not well explained by variation in the regulatory environment.

The final body of research on the insurance cycle supported a hypothesis that a lagged negative feedback loop within the insurance industry was the cause of the cycle. Since past information must be used for determining present prices, and since these prices are only revealed to be profitable or unprofitable once losses are realized, a simple discrete time model of the premium-setting process in the insurance industry will produce a cyclical output (Venezian 1985). Later work made the connection between this price-setting process and the total surplus capital of the insurance company (Berger 1988). When this link is included in a model, it completes an additional negative feedback loop, since profits increase the capital surplus, which increases competition in the industry, driving prices down and eventually lowering profits.

While this research approach was promising, it suffered from several limitations that kept it from dominating the debate on the causes of the insurance profit cycle (Doherty and Garven 1995). The first limitation was that all of the models published were made analytically tractable by grouping the negative feedback processes they modeled into a very small number of effects. This meant that researchers could not differentiate between the various hypotheses for the cause of cycles in the insurance industry, because each model had to largely exclude the insights from the others. The second limitation was that, because these models excluded the effects of exogenous variables on the profitability of insurers, they could not respond to the research that suggested that cyclical profits were the result of fluctuations in interest rates or other exogenous variables.

From the standpoint of these research efforts this essay lies within, and extends, the third body of work by seeking to explain the insurance cycle through the modeling of endogenous feedback processes. My approach addresses the limitations mentioned above by numerically simulating, rather than analytically solving, the differential equations within the model. This approach allows me to build a model with a richer structure and appropriate exogenous forcing. Competing hypotheses about which macroeconomic fluctuations or specific feedback loops are the most important for causing the profit cycle in the insurance industry can therefore be evaluated here.

Research on the insurance industry has also been a feature of the system dynamics literature, but these papers have largely dealt with managing the quality of the claim adjustment process. Starting with the learning laboratory built for Hanover Insurance,<sup>4</sup> researchers noticed that the low salience of soft variables associated with insurance claim adjusting made the quality of settlements less important to managers than the total productivity of their workforce. This incentivized managers to increase the workload on adjusters, which led to an erosion of the quality of settlements,<sup>5</sup> and raised the total costs of insurance companies (Morecroft 1988; Senge and Sterman 1992). Later studies have taken this theory of service delivery dynamics and applied it to many different settings, including health care (Homer and Hirsch 2006), Toyota's Total Quality Management (Repenning and Sterman 2001) and the service industry in general (Oliva and Sterman 2001). The implementation of system dynamics to solve

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<sup>4</sup>See Sterman and Moissis (1989)

<sup>5</sup>Quality here is taken to be a measure of the size of the payment relative to some unknown payment size that the customer would accept at minimum. higher quality means lower cash outlays for claims.

the problems at Hanover Insurance was an early instance that showed the power of the technique and was cited as a good example of how system dynamics can be used to change the mental models and behavior of managers (Cavaleri and Sterman 1997).

The dynamics of service quality erosion have been applied in many different contexts within the insurance industry (Doman et al. 1995). But surprisingly, the system dynamics literature has not expanded its focus on insurance to explore the question of how the profit cycle in the insurance industry arises. This essay is not without precedent, since the topic of profit cycles has been extant in system dynamics research for decades.

Cyclical profit dynamics in the commodity markets (Meadows 1970), paper makers (Berends and Romme 2001), airlines (Liehr et al. 2001), and the economy as a whole (Forrester 1991; Sterman 1986) have all been addressed with dynamic modeling, but the vast majority of earlier attempts focused on industries with long lags in capacity adjustment. Because capacity decisions are made using current profit signals, and the appropriateness of their decisions will not be known until capacity is built, the capacity adjustment delay has been widely cited as a cause of profit cycles. While delays still play a role in the insurance profit cycle, the capacity adjustment delay does not, and so the setting of this essay places it apart from existing research.

### 3.3 Data Sources

I compile aggregate financial statement data for all firms in the Compustat Fundamental Annual Data Files that have SIC code 6331.<sup>6</sup> Many of these firms are diversified into businesses unrelated to property casualty insurance, and so I only use data classified as “non-life” when calibrating the model. For instance, instead of calibrating the model using total premiums collected by all firms in the industry, I use the separate data item for total non-life premiums collected. Because this more disaggregated data is only available after 1982 only the data from 1982 through 2009 is used during model calibration. Investment results, total capital and several other variables are not recorded in this way, and so I use them only when appropriate for estimation of model parameters and tests of the correlation of the model over a long time horizon. Specifics on the time series I use can be seen in table 3.1. Two other data series that I use are quarterly nominal GDP for the United States, and average Baa-rated bond yields. These series come from the United States Bureau of Economic Analysis.

### 3.4 Causal Structure

Figure 3-2 shows two important balancing feedback loops in my model of the insurance industry. When the stock of capital on hand is large relative to some target, insurers will seek to expand the scope of their offerings by branching out into types of policies

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<sup>6</sup>Standard Industry Classification 6331. Fire, Marine, and Casualty Insurance.

Data	Description	Usage	Notes
Operating Income	"Non-life" Income	All	Insurance companies report investment income as "operating"
Premiums Collected	"Non-life" Total Premiums	All	
Claims Incurred	"Non-life" Claims	All	
Nominal GDP	From the BEA	All	All financial data used is nominal.
Claims Expense	"Non-life" Claims Expense	Corr	See section 3.5.4 for the relationship between claims incurred and claim expense.
Dividends	All firms in SIC 6331	Corr	Only reported at a firm level.
Assets -Total	All firms in SIC 6331	Corr	Only reported at a firm level.
Invested Capital	All firms in SIC 6331	Corr	Only reported at a firm level.
Investment Income	All firms in SIC 6331	Corr	Only reported at a firm level.
Total Expenses	All firms in SIC 6331	Corr	Only reported at a firm level.
Total Liabilities	All firms in SIC 6331	Corr	Only reported at a firm level.
Shareholder's Equity	All firms in SIC 6331	Corr	Only reported at a firm level.
Commissions	All firms in SIC 6331	Corr	Only reported at a firm level.

**Table 3.1:** This table is a short description of the data used during model formulation, calibration and testing. Premiums, claims and income were available at the level of the "non-life" insurance industry, while most of the data were only available for the aggregate four-digit SIC code. Because of this, most of the data was used only for testing of correlations as shown in table 3.6 and section 3.8. For all of these tests I am assuming that the property-casualty industry represents a constant fraction of the total insurance industry. This is obviously not the case, and to the extent this assumption is incorrect the correlations reported will be biased towards zero.

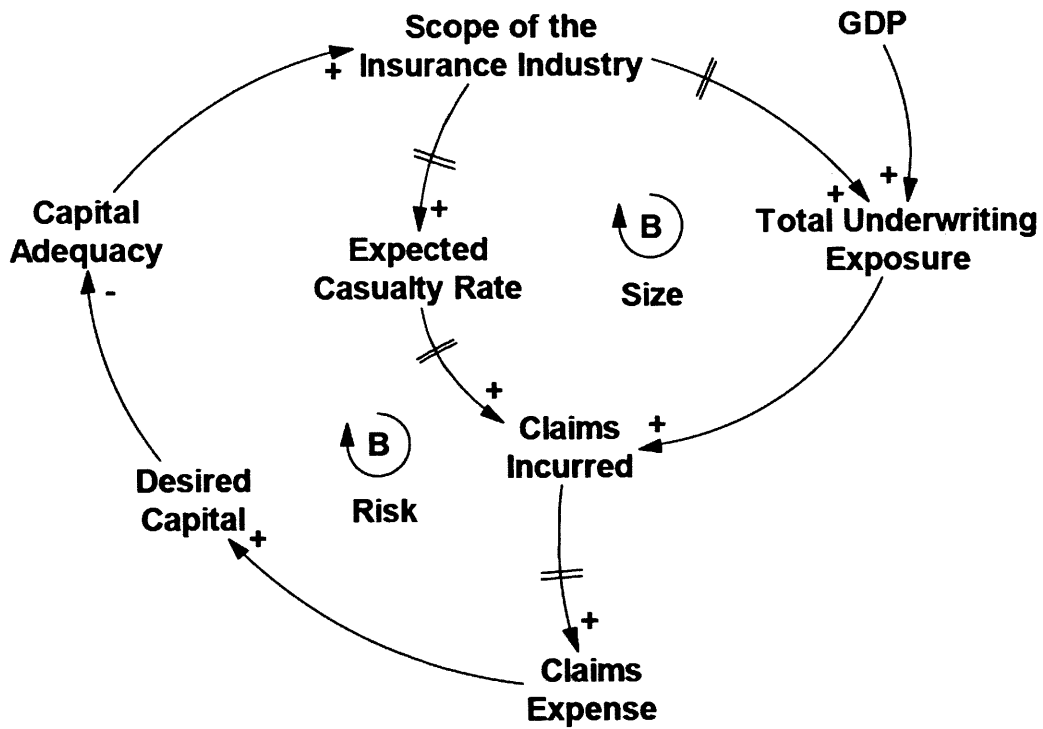
that they are less familiar with. A study by Ericson and Doyle (2004) describes this effect well, and from many angles. For instance, they write:

"One option for insurers faced with uncertainty is to simply refuse to participate in underwriting a particular risk.... Refusal to participate in particular risks also occurs in the process of excluding certain populations from a given insurance pool because they threaten the integrity and profitability of that pool. (2004:17)"

During lean times insurers will look to scale back the types of policies they write by focusing only on the populations where they feel that they have sufficient data to price the risk correctly<sup>7</sup>. In aggregate, this causes the overall value of the property insured to fall. When insurers are well capitalized the opposite happens, as each individual company puts some of its money to use writing policies for clients that it would otherwise avoid because of the high uncertainty of the underlying risk<sup>8</sup>. This adjustment of insurance scope results in an increase in the total underwriting of the industry as well as an increase in the riskiness of the policies written<sup>9</sup>, forming the two closely related "Size" and "Risk" balancing loops, respectively.

Both of the loops in figure 3-2 can also be thought of as arising in part from changes in the price of insurance not captured by total premiums. Smith (1981) and many other scholars in this area discuss the problem that arises out of using premiums

<sup>7</sup>One of the features of the 1980's insurance crisis was the inability of consumers to find insurance. See Cagle and Harrington (1995) for a capacity-constrained model of that dynamic, Cummins and Lewis (2003) for a discussion of the effect in the case of terrorism insurance, and Winter (1991) for



**Figure 3-2:** A causal loop diagram of two delayed balancing loops that describe how increases in the adequacy of capital for the insurance industry lead to expansions in the size of the industry as well as the level of risk taken. These two feedback loops result in capital being less adequate than it otherwise would have been.

as a measure of price, given that the industry employs numerous other incentives when marketing policies. For instance, if deductible increases are implemented as a response to rising cost expectations, the net effect will be a reduction of both the size of claims incurred and the total underwriting exposure compared to what they would be otherwise. Claims will be reduced on new policies because a larger fraction of the loss is covered by the deductible, while exposure will be reduced because the marginal customer will be less likely to insure their assets.

Figure 3-3 shows another set of balancing loops that result from the expansion of the scope of the industry in my model. Each of these loops is caused by the increase in various components of cost<sup>10</sup>. As costs increase, operating profits fall; *ceteris paribus*, total capital therefore decreases, and capital adequacy becomes lower than it otherwise would have been<sup>11</sup>. This acts to balance the initial expansion of the industry through the balancing “Costs” feedback loop.

Figure 3-4 brings premiums into the causal structure and completes several new feedback loops. First, excess capital can cause insurers to compete for market share in areas where they already have a presence.<sup>12</sup> This competition reduces premium income, which acts through operating income to make the stock of capital lower than it otherwise would have been, and thus balances the initial increase in capital through the “Price War” balancing feedback loop.

The increases in cost from the scope of the industry also influence premiums. Insurers update information about their claims and expenses, forecast them, and use that information to ensure that they are pricing policies correctly to guarantee future profitability.<sup>13</sup> This “Profit” reinforcing loop acts through the same causal path as the “Price War” loop but in the opposite direction, and reinforces the signal to expand the scope of the industry by keeping prices high enough to justify the added risks. The “Price war” and “Profit” loops are difficult to see clearly in figure 3-4, and so are shown separately in a simplified causal loop diagram in figure 3-5.

Figure 3-6 completes the causal loop diagram of my model by incorporating a set of financial feedback loops stemming from net income and dividends. Income increases total capital,<sup>14</sup> and with a short delay capital is invested and contributes to net income through investment, completing the “Interest” reinforcing loop. The effect of the “Return on Shares” balancing loop created by dividend payments is mitigated somewhat by a counteracting “Return on Equity” reinforcing loop that captures the opportunity cost to shareholders of dividend disbursements. If the income of the

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an overview of the experience during the 1980's.

<sup>8</sup>See Myers and Read (2001) as well as section 3.5.4.

<sup>9</sup>Discussions with industry professionals also indicate that scope changes have an effect on the measurement uncertainty of the underlying risk. When scope expands, insurers have less data, on balance, about the policies they are writing. For a description of the expansion of scope in my model and a justification of this causal link, see section 3.5.6.

<sup>10</sup>A discussion of how I model the components of cost can be found in section 3.5.5.

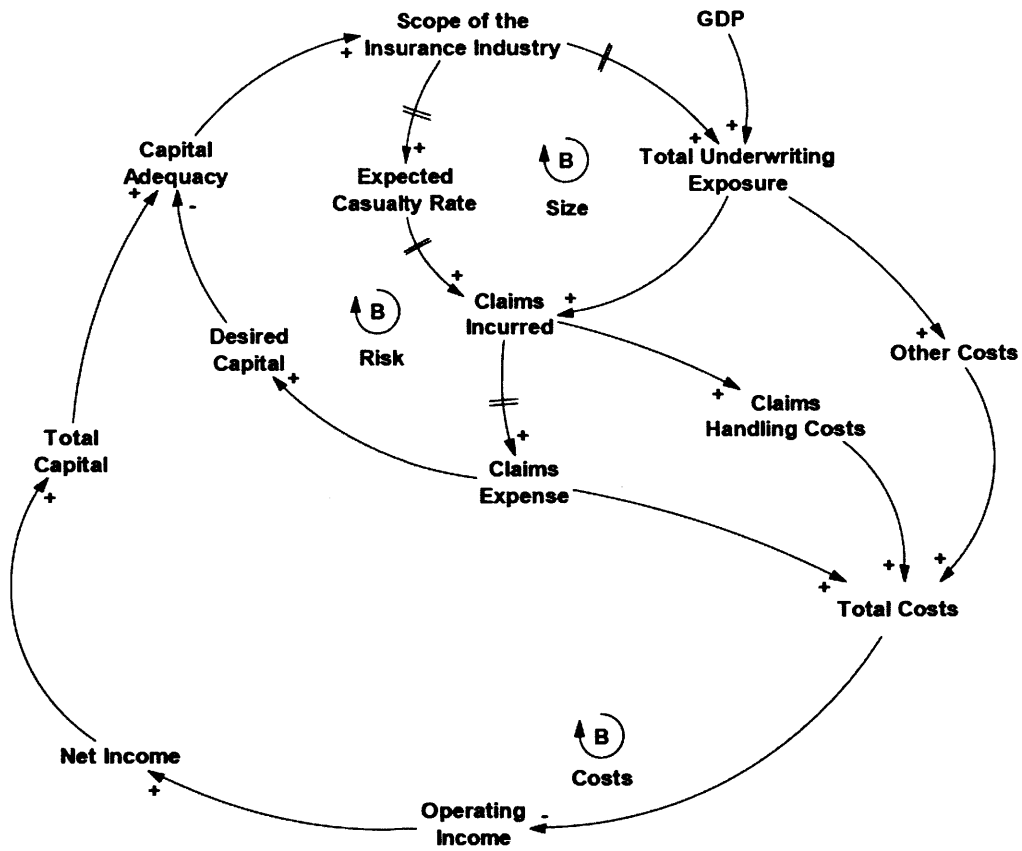
<sup>11</sup>These are all mechanical results of the definition of profit, and the stock of total capital.

<sup>12</sup>Pauly (1974) is a frequently cited early example of price competition in the insurance industry.

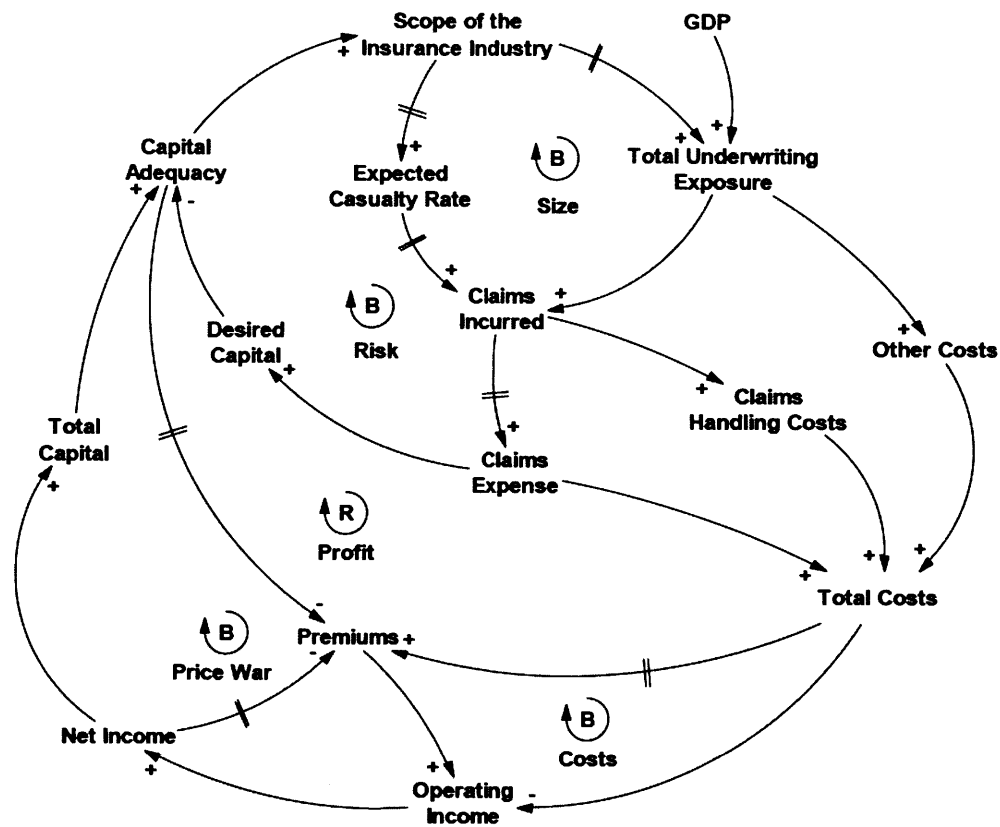
<sup>13</sup>Cockley et al. (2001) or any practitioner-oriented book on the insurance industry will provide numerous examples of the process of forecasting insurance underwriting costs.

<sup>14</sup>This occurs mechanically, through its definition and the definition of the stock of total capital.

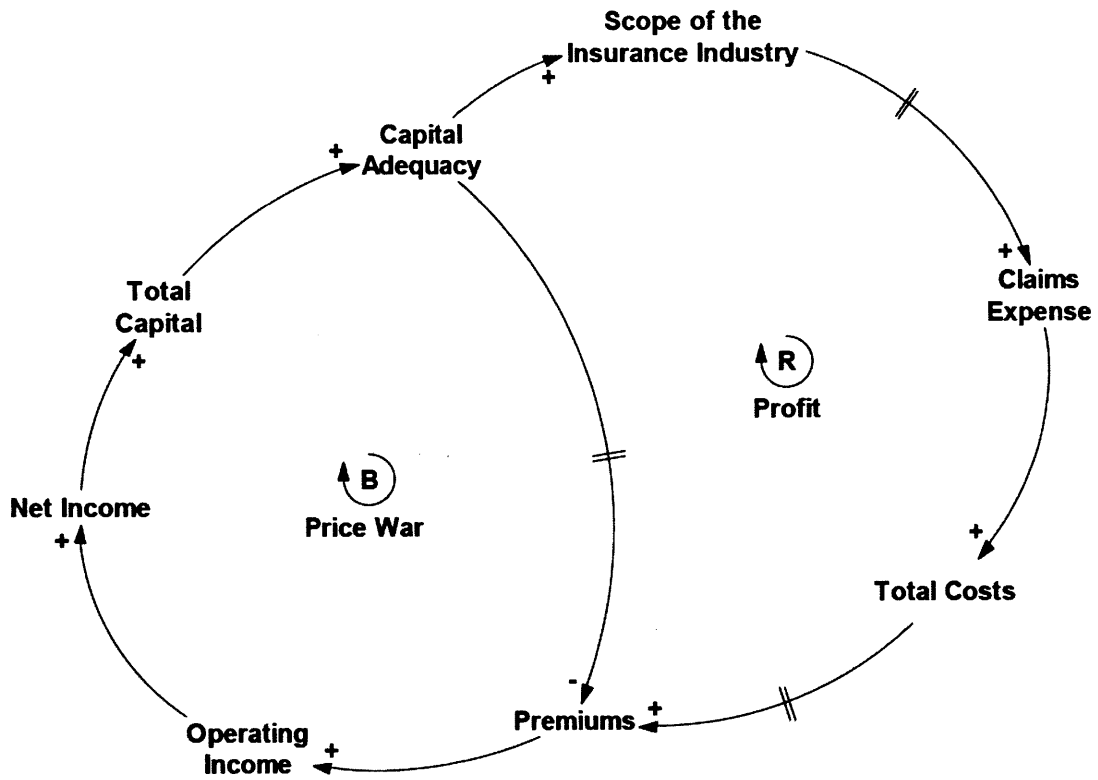




**Figure 3-3:** When costs are added to the causal map the effects of increasing scope become more important for the model's behavior. Costs complete another set of strong negative feedback loops with significant delays caused by inertia in the the book of underwriting.



**Figure 3-4:** Premiums complicate the causal structure slightly, as they introduce the first reinforcing loop to the diagram. Because premiums respond to changes in costs, their effect is partly to help sustain the expansion of scope and costs caused by capital adequacy. This intended rationality is counterbalanced by an additional balancing loop that describes how capital adequacy itself can keep premiums from rising through the action of intense competition between insurers over market share.



**Figure 3-5:** This figure shows a subsection of figure 3-4. In this simplified diagram the reinforcing action of profit to justify changes in insurance scope is shown in the “Profit” loop. The compensating action of price competition is shown in the “Price War” loop.

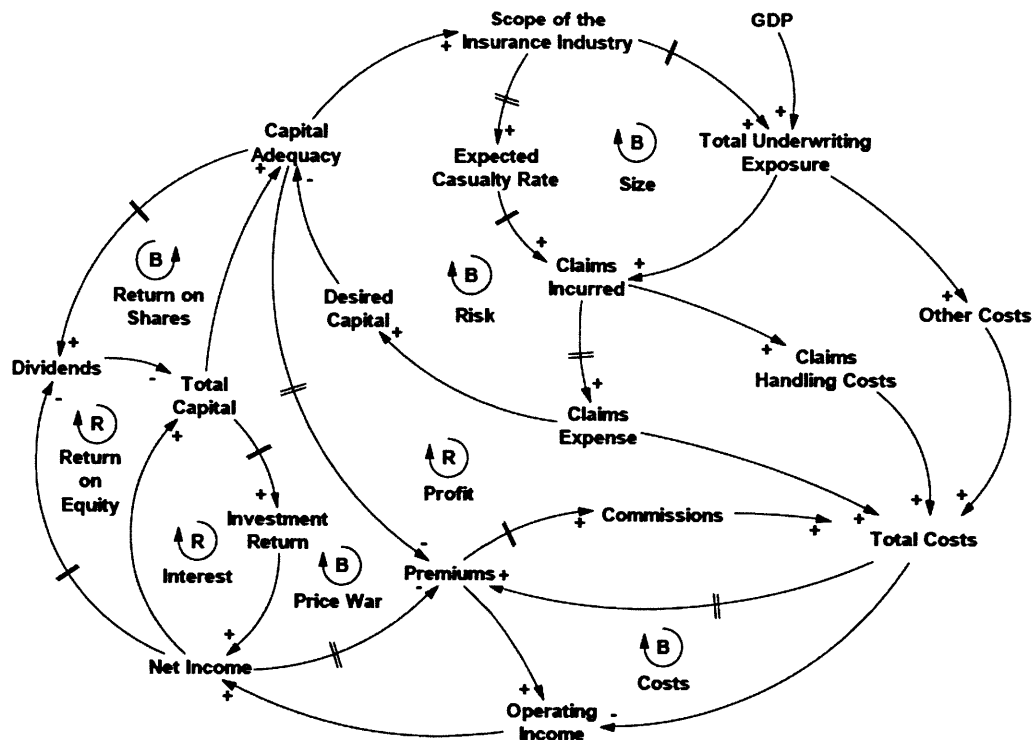


Figure 3-6: The final causal loop diagram for the insurance industry model, which includes loops around dividends and investment.

insurance industry is high, dividends will be limited so that capital can be reinvested in the business.<sup>15</sup>

### 3.5 Model Formulations

The model for the insurance industry starts with a parsimonious formulation for profit shown in equation 3.1:

$$N_t = R_t - C_t - O_t \tag{3.1}$$

Where  $N_t$  is current net income  $R_t$  is total revenue  $C_t$  is claims expense and  $O_t$  is other operating costs. The formulation for each of these components will be explained in detail in the following sub-sections.

#### 3.5.1 Premiums

Millions of dollars are spent every year by insurance companies to ensure that the premiums they charge are adequate to cover the costs they will incur from claims, their

<sup>15</sup>See Bringham and Gordon (1968), or section 3.5.8.

operating costs, and a reasonable profit margin. Understandably, the exact heuristics behind the pricing of insurance are a closely guarded secret and involve volumes of data on hazard rates that are not available to academics. Many practitioner-oriented texts do exist, and the basic process of rate making described by them is not significantly different from the process of price setting in other industries. For example, Cockley et al. (2001:83) supply an equation to determine the rate per unit exposure on page 83 of their book:

$$Pr = \frac{P_p + F}{1 - V - Q} \quad (3.2)$$

Where  $Pr$  is the premium rate charged per dollar of underwriting,  $P_p$  is the pure premium,<sup>16</sup>  $V$  is an adjustment for variable costs, and  $Q$  is a factor that builds in a profit margin. My model incorporates the concept behind this description of the price-setting process, but translates some of the influences on premiums into functional forms more familiar in the system dynamics literature.

The average premium-per-dollar of underwriting exposure charged by the insurance industry is influenced by the costs they expect to bear in servicing the policy.<sup>17</sup> Many texts on the rate-making process in the insurance industry advocate for insurance adjusters to project this cost forward to account for changes in the value of future expenses. Therefore my model takes the costs calculated by the structures described in sections 3.5.4 and 3.5.5 and projects their perceived value forward using the standard third-order forecasting structure to arrive at the expected cost-per-unit underwriting<sup>18</sup>. This variable is then used as part of a multiplicative hill-climbing heuristic (Sterman 2000) in the following way.

First, an indicated premium is calculated as shown in equation 3.3:

$$TPR_t = (Pr_t) \cdot Ef^{NI} \cdot Ef^{Cap} \cdot Ef^{Cost} \quad (3.3)$$

Where  $TPR_t$  is the indicated premium,  $Pr_t$  is the current premium per unit exposure,  $Ef^{NI}$  is the effect of profit on premiums,  $Ef^{Cap}$  is the effect of capital on premiums and  $Ef^{Cost}$  is the effect of cost on premiums. Conceptually,  $Ef^{Cost}$  can be thought of as the change in the premium indicated by the forecasted costs discussed above. It is calculated as the ratio of forecasted costs to current perceived costs.<sup>19</sup> Consequently if costs were expected to rise by some percentage, then the indicated premium would be higher than the current premium by exactly the change in cost expected during the policy lifetime.

$Ef^{NI}$  and  $Ef^{Cap}$  are both formulated as power functions that take as their input the current state of the variable in question compared to a “target” state.  $Ef^{Cap}$  is calculated according to equation 3.4:

<sup>16</sup>Pure premium is the term used in the insurance industry to represent the expected claim expense plus the expected costs of claims adjustment. In my model these concepts are kept separate to increase transparency for academics unfamiliar with insurance industry terminology.

<sup>17</sup>See Cockley et al. (2001), or look up the term “trended projected ultimate losses”.

<sup>18</sup>This projected value represents the influences from  $P_p$ ,  $F$ , and  $V$  in equation 3.2.

<sup>19</sup>More precisely I use the “expected” current costs as the basis for the forecast, since decision makers do not have access to the current “true” value of costs-per-unit exposure.

$$Ef^{Cap} = (CapA)^{S_{Pr2Cap}} \quad (3.4)$$

Where  $CapA$  is the adequacy of capital described in equation 3.10 and  $S_{Pr2Cap}$  is the constant sensitivity of premiums to capital. Given this formulation  $S_{Pr2Cap}$  should be negative, because more capital adequacy will result in downward pressure on premiums.

The effect of profit on premiums is calculated according to equation 3.5:

$$Ef^{NI} = (In^{Adq})^{S_{Pr2NI}} \quad (3.5)$$

Where  $In^{Adq}$  is the adequacy of income and  $S_{Pr2NI}$  is a constant sensitivity of premiums to net income. Similar to the effect of capital on premiums, the causal theory behind my model necessitates that  $S_{Pr2NI}$  be negative in order for higher income to translate into lower premiums.  $In^{Adq}$  is:

$$In^{Adq} = \frac{(1 + ROA)}{(1 + TROA)} \quad (3.6)$$

Where  $ROA$  is the current level of industry return on assets and  $TROA$  is the target return on assets, a constant determined during model parametrization.  $ROA$  and  $TROA$  are fractions, and since it is possible that the model could calculate an  $ROA$  that is less than negative one,  $In^{Adq}$  could be less than zero, and the formulation in equation 3.6 would return a floating point error. In order to prevent this from occurring, I employ a sharp maximum so that the lowest possible level of the income adequacy in the model is zero. Given this formulation, if the modeled industry were to lose more money in a single year than it had in total assets, the model would still empty the stock of assets and bankrupt the industry, but the floating point error in calculating income adequacy would be eliminated.

I accomplish the adjustment of premiums towards the indicated level with equation 3.7:

$$Pr_t = \int \left[ \frac{(TPr_t - Pr_t)}{\tau_P} \right] dt + Pr_0 \quad (3.7)$$

Where  $Pr_t$  is the current premium per unit exposure charged on average,  $\tau_P$  is the delay time associated with changing premiums,  $Pr_0$  is the initial premium per unit exposure and  $TPr_t$  is the premium indicated from equation 3.3. The instantaneous premium  $Pr_t$  is then recorded in a co-flow to the aging chain of total underwriting exposure, and the total premium income of the industry is calculated as:

$$PrInc = Pr^{Avg} \cdot U_t \quad (3.8)$$

Where  $PrInc$  is the flow of premium income,  $Pr^{Avg}$  is the average premium per unit exposure calculated by the co-flow, and  $U_t$  is the total underwriting exposure of the industry, discussed in section 3.5.6.

### 3.5.2 Capital Adequacy

One of the liquidity ratios used by analysts and regulators covering the insurance industry is the “claims solvency ratio” or:

$$CSR = \frac{CI_t}{PrInc} \quad (3.9)$$

Where  $CSR$  is the claims solvency ratio, and  $CI_t$  is the flow of claims incidence for the industry. I do not directly compute the claims solvency ratio for determining capital adequacy; rather, adequacy of capital in the model is calculated following equation 3.10:

$$CapA = ZIDZ\left(\frac{Cap}{DCap}\right) \quad (3.10)$$

Where  $CapA$  is the adequacy of capital,  $ZIDZ$  is the “zero if division by zero” operation,  $Cap$  is the current total capital of the industry and  $DCap$  is the current desired capital, calculated as shown in equation 3.11:

$$DCap = DCSR \cdot CI_t \quad (3.11)$$

Where  $DCSR$  is the desired claims solvency ratio, which is a constant estimated during model calibration.

### 3.5.3 Investments and Capital

I model the stock of investment capital as shown in equation 3.12:

$$Cap_t = \int (OCF + Inv - Div)dt + Cap_0 \quad (3.12)$$

Where  $Cap_t$  is the current total capital,  $OCF$  is the operating cash flow<sup>20</sup>,  $Inv$  is the flow of investment income,  $Div$  is the flow of dividends being paid to shareholders, and  $Cap_0$  is the initial capital stock of the industry. The flow of investment income is calculated as shown in equation 3.13:

$$Inv = Cap_t \cdot R\% \quad (3.13)$$

Where  $R\%$  is the percentage return on investment gained by the insurance in industry each year. The formulation for the percentage return on investments is exogenous, and a detailed description of how it is modeled is included in the section 3.6.2. For the process of fitting the model to historical data, the percentage return

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<sup>20</sup>Because I exclude depreciation, taxes and physical capacity from the model, there are no flows from these sources, making operating cash flows an appropriate name for the flow recorded here. The financial data for the insurance industry includes investment income in operating income, and so throughout this chapter I use net income and operating income interchangeably to refer to that concept. In the model, operating cash flow is separate from net income in order to make my formulations general enough for future modelers to extend.

on invested assets was set to be the historical investment return.  $R_t$  from equation 3.1 is then:

$$R_t = Pr^{Avg} \cdot U_t + Cap_t \cdot R\% \quad (3.14)$$

### 3.5.4 Claims Costs

The total dollar value of claims incurred by the insurance industry is shown in equation 3.15:

$$CI_t = U_t \cdot LF_{avg} \cdot (1 + \varepsilon) \quad (3.15)$$

Where  $CI_t$  is the flow of claims incurred by the industry,  $U_t$  is the total underwriting exposure of the industry,  $LF_{avg}$  is the average fraction of dollars underwritten that result in a claim each year and  $\varepsilon$  is an exogenous noise term that is only used in the long-horizon statistical tests of the model, explained in section 3.8. The determination of the total underwriting exposure is described in subsection 3.5.6.

The percentage of underwriting that generates a claim is not constant in the model. As discussed in section 3.5.6 and 3.4, insurers seek out more business when they are more financially healthy, and in the process insure risks that have both a higher absolute level of exposure<sup>21</sup> and a higher exposure measurement uncertainty.

The specific functional form for the riskiness of new policies in the model is a constant normal level of loss, multiplied by an adjustment factor that varies as a power function of the normalized scope of the industry. This relationship is shown in equation 3.16.

$$LF_t = NLF \cdot \left(\frac{Sc_t}{NSc}\right)^{Sc_{CR2SC}} \quad (3.16)$$

Where  $NLF$  is the normal underwriting loss fraction, and is estimated during model calibration,  $Sc_t$  is the current scope of the industry,  $NSc$  is the normal scope, and  $Sc_{CR2SC}$  is the sensitivity of the casualty rate to insurance scope. This loss fraction is applied only to newly underwritten policies, and is recorded in the co-flow structure for the riskiness of current underwriting. The average loss fraction for the entire book of underwriting business is calculated using a co-flow of the total dollars underwritten<sup>22</sup> to arrive at  $LF_{avg}$ .

Claims incurred then flow into a stock of pending claims, as shown in equation 3.17:

$$CP_t = \int (CI_t - C_t - CD_t)dt + CP_0 \quad (3.17)$$

Where  $CP_t$  is the stock of claims pending adjustment,  $C_t$  is the claims expense,  $CD_t$  is the flow of claims that are denied and  $CP_0$  is the initial level of pending

<sup>21</sup>Level of exposure here means the fraction of dollars underwritten that will result in a claim every year. I use this term interchangeably with "casualty rate."

<sup>22</sup>See Sterman (2000).



claims. Claims expense and claims denied sum together to the outflow from a first-order material delay of  $CP_t$  such that:

$$\frac{CP_t}{\tau_C} = C_t + CD_t = F_{CP} \cdot \frac{CP_t}{\tau_C} + (1 - F_{CP}) \cdot \frac{CP_t}{\tau_C} \quad (3.18)$$

Where  $\tau_C$  is the average delay in adjusting claims and  $F_{CP}$  is the fraction of claims that are paid. I estimated the fraction of claims paid with a regression of non-life insurance claims incurred on total non-life claims expense. The result, that 84.7% of claims are paid on average, was highly statistically significant, with a standard error of 0.02 on an estimate of 0.847 and an  $R^2$  of 95%.

### 3.5.5 Other Operating Costs

In formulating “other operating costs” I assume that costs primarily arise from claims-handling costs and commissions. Claims-handling costs represent all of the administrative costs arising from claims, and are modeled as a constant fraction of the flow of adjusted claims, as shown in equation 3.19:

$$Cost_{CH} = CP_t \cdot F_{CHC} \quad (3.19)$$

Where  $Cost_{CH}$  is the costs arising from handling claims and  $F_{CHC}$  is the fractional cost of handling one dollar of claims. The justification for this formulation comes from the Hanover Insurance “Claims Game” documented by Sterman and Moissis (1989)<sup>23</sup>, where the authors make the simplifying assumption that the administrative costs from claims adjustment varies linearly with the number of cases. Since my model is less concerned with the details of how costs from claims vary in time, the same assumption here should have little effect on the model’s fit.

Commissions are a common practice in the insurance industry, and are paid to independent insurance agents after they persuade a customer to buy a policy<sup>24</sup>. Most commissions are paid in the first year that the policy is active, and are built into the premium paid by the customer; however, some commission payments continue for multi-year policies and renewals. With this in mind, I model commissions as a material delay of deferred commission payments, proportional to the inflow of premiums written. The flow of commission expenses use an empirically estimated delay time, as shown in equations 3.20 and 3.21 :

$$Com_P = \int (Pr_{New} \cdot F_{PCC} - Cost_{Com})dt + Com_0 \quad (3.20)$$

$$Cost_{Com} = \frac{Com_P}{\tau_{Com}} \quad (3.21)$$

<sup>23</sup>See page 68, table 6

<sup>24</sup>See Regan and Tennyson (1996) for a description of the commission system in property-casualty insurance.

Where  $Com_P$  is the deferred liability of commission costs pending,  $Pr_{New}$  is the flow of new premiums written<sup>25</sup>,  $F_{PCC}$  is the fractional cost of commissions per dollar of new premiums written,  $Cost_{Com}$  is the flow of actual commissions costs being paid,  $Com_0$  is the initial level of pending commissions costs<sup>26</sup>, and  $\tau_{Com}$  is the average delay for commissions payments.

### 3.5.6 Demand for Underwriting

Conceptually, the demand for insurance should be proportional to the stock of assets in the economy. Unfortunately the stock of assets in the economy is not a variable that is easily measurable, and so reliable data on its level are not available. For this reason, many academics researching insurance assume that the demand for insurance is proportional to the flow of investment, which is some unknown fraction of the gross domestic product<sup>27</sup>. Therefore my model uses the nominal gross domestic product as the basis for the demand for underwriting. Some fraction of that flow is considered to represent investment in insurable assets, creating a stock that proxies for the assets in the economy, as shown in equations 3.22 and 3.23:

$$A_t = \int (GDP_t - \frac{A_t}{\tau_A}) dt \quad (3.22)$$

$$Assets = F_{GDP2Un} \cdot A_t \quad (3.23)$$

Where  $Assets$  is the proxy my model uses for the level of assets in the economy,  $F_{GDP2Un}$  is the fraction of the annual GDP that represents those assets,  $\tau_A$  is the average life of capital<sup>28</sup>,  $A_t$  is an intermediate stock that accumulates the flow of GDP and the flow of assets being removed from the pool of insurable capital and  $GDP_t$  is the flow of exogenous, nominal gross domestic product. This level of assets desiring insurance does not directly represent the demand for dollars of underwriting however, as other important effects must be taken into account.

$$DesIns_{Consumer} = Assets \cdot Ef^{PE} \quad (3.24)$$

Equation 3.24 shows the effect of premiums on the proportion of the assets from equation 3.22 that are insured.  $Ef^{PE}$  represents the effect of the price elasticity of demand for insurance, and its inclusion should be justified briefly. Many previous studies on the insurance industry have assumed that demand for liability insurance is price inelastic, and that assertion has been supported by empirical studies<sup>29</sup> as

<sup>25</sup>This flow is collected in a co-flow of written premiums that follows a standard formulation for a co-flow with aging chain. More information on these formulations is available in the appendix.

<sup>26</sup>Set in dynamic equilibrium to be  $\tau_{Com} \cdot Pr_{New} \cdot f_{PCC}$ , by Little's Law

<sup>27</sup>See Smith (1981) among others.

<sup>28</sup>There is no reason to assume that the average life of capital in my model is identical with the actual physical life of capital in the economy or with the life of capital assumed for depreciation. Here the concept is the "insurable" life of capital, i.e. the length of time on average capital investments will be considered as worthy of insurance by their owners.

<sup>29</sup>See for example: Cagle and Harrington (1995), Strain (1966) and Weiss and Chung (2004)

well. Automobile insurance, homeowners insurance, and marine insurance are often mandatory, and so changes in the cost of insurance will shift the distribution of customers between companies in the industry but will have a relatively small effect on the overall demand for insurance until price changes become so extreme that they influence demand for the underlying goods being insured<sup>30</sup>. Rather than assume that the price elasticity is zero however, it is better practice to include the elasticity of demand to price and let model calibration determine the value of the parameter. The exact formulation for the effect of price on demand that I use in the model is shown in equation 3.25:

$$Ef^{PE} = \left(\frac{Pr_t}{Pr_{Ini}}\right)^{\eta_P} \quad (3.25)$$

Where  $Pr_t$  is the current premium per dollar of exposure,  $Pr_{Ini}$  is the normalizing initial premium charged per dollar of exposure and  $\eta_P$  is the price elasticity of demand.

The demand for insurance is also affected by the income elasticity of demand. Consumer income in the model is proxied for by the exogenous GDP, and normalized by GDP's initial level, as shown in equation 3.16:

$$Ef^{Inc} = \left(\frac{GDP_t}{GDP_{Ini}}\right)^{\eta_I} \quad (3.26)$$

Where  $GDP_t$  is the current nominal GDP,  $GDP_{Ini}$  is the normalizing initial GDP and  $\eta_I$  is the income elasticity of demand, which is positive. This effect combines with the price elasticity of demand to arrive at the adjusted desired level of insurance as shown in equation :

$$DesIns = DesIns_{Consumer} \cdot Ef^{Inc} \quad (3.27)$$

Two important concepts for the determination of the demand for insurance have now been calculated by the model. The first is the level of insurance *a priori*, and the second is the level of demand for insurance that can actually be served by the industry after considering price and income effects. Once the model has calculated this desired level of insurance, the calculation of the inflow to the aging chain for total underwriting exposure is accomplished by way of the standard stock management structure, as shown in equation 3.28:

$$U_{in} = Max\left(\frac{DesIns - U_t}{\tau_U} + U_{Out}, 0\right) \quad (3.28)$$

Where  $U_{in}$  is the inflow of underwriting to the industry,  $Max$  denotes the maximum function,  $U_t$  is the current level of total underwriting exposure<sup>31</sup>,  $\tau_U$  is the delay in adjusting underwriting to its desired level and  $U_{Out}$  is the outflow of underwriting, analogous with replacement purchases in the stock management formulation.

<sup>30</sup>Feldblum (1999) describes the price elasticity of demand for property liability insurance in detail.

<sup>31</sup>Underwriting is tracked by a third order aging chain in the model, for more information on this formulation please see the appendix.

### 3.5.7 Scope

The “scope” of the industry is an important feature of my model and has already been discussed conceptually in section 3.4. The mathematical formulation for this effect is the smooth adjustment of scope towards an indicated scope that is multiplicatively influenced by two effects:

$$Ef_{Cap2Sc} = (CapA)^{Sc_{ap2Sc}} \quad (3.29)$$

$$Ef_{Inc2Sc} = (In^{Adq})^{S_{Inc2Sc}} \quad (3.30)$$

Where  $Ef_{Cap2Sc}$  is the effect of capital on scope,  $CapA$  is the capital adequacy of the industry discussed in equation 3.10,  $Sc_{ap2Sc}$  is a constant denoting the strength of the relationship between capital and scope,  $Ef_{Inc2Sc}$  is the effect of income on scope,  $In^{Adq}$  is the adequacy of income measured according to equation 3.6, and  $S_{Inc2Sc}$  is the strength of the relationship between income and scope. The indicated scope is an adjustment around a constant normal level using the structure shown in equations 3.31 and 3.32:

$$Sc_{Ind} = Sc_{Norm} \cdot Ef_{Cap2Sc} \cdot Ef_{Inc2Sc} \quad (3.31)$$

$$Sc_t = \int \left( \frac{Sc_{Ind} - Sc_t}{\tau_{Sc}} \right) dt + Sc_{Ref} \quad (3.32)$$

### 3.5.8 Dividends

The model’s formulation of dividend policy is extremely parsimonious. Dividends in the model are simply a constant fraction of net income, constrained to always be a positive number, as shown in equation 3.33:

$$Div = Max(N_t \cdot Div_{Ratio}, 0) \quad (3.33)$$

Where  $Div_{Ratio}$  is the constant dividend payout ratio,  $Max$  denotes the sharp maximum function,  $N_t$  is the flow of net income from equation 3.1 and  $Div$  is the dividend payment flow. Because dividends only affect net income indirectly through their effect on the stock of invested assets a more complex formulation was prohibitive given my model’s focus. Initially the insurance industry model had a formulation for dividends based off of Stermann (1981), however extensive testing revealed that the net effect of the formulation was to hold dividends at a roughly constant fraction of net income.

### 3.5.9 Exclusion of Reserves for Claims

Reserves are an important concept for insurance executives. Regulators require insurance companies to estimate reserves against foreseeable losses in many areas, and the companies are required to account for these reserves as liabilities on their financial statements. I choose to exclude these reserves from my model for several reasons.

	Estimate	Standard Error	t-stat	$R^2$
Constant	-22.7	7.2	-3.1	97.2%
$CI$	3.81	0.126	30.25	

**Table 3.2:** The equation for the regression reported is  $CRes = \alpha + \beta \cdot CI + \varepsilon$  run over the period from 1982 through 2009.  $CRes$  is aggregate claims reserves reported and  $CI$  is aggregate claims incurred.

First, the data suggest that reserves are not very interesting dynamically. Econometric analysis of reserves for claims shown in table 3.2 indicates that they can be modeled in aggregate by a linear function of the claims expense.

The second reason is more operational. While reserves are treated as liabilities by accountants, they are liabilities in an accrual sense only, and so they are still contributing to the investment income of the insurance industry until they are realized as negative cash flows. From the standpoint of my model the inclusion of reserves would have been simple, but would have added nothing of causal importance.

## 3.6 Parametrization of the Statistical Properties of the Exogenous Inputs

### 3.6.1 Gross Domestic Product

The model uses nominal GDP to drive the demand for insurance, as described in section 3.5.6. In order to perform tests of the statistical properties of the feedback structure in the model shown in section 3.8 I analyzed the statistical properties of nominal GDP and designed a random process using this analysis that could stand in for the historical time series.

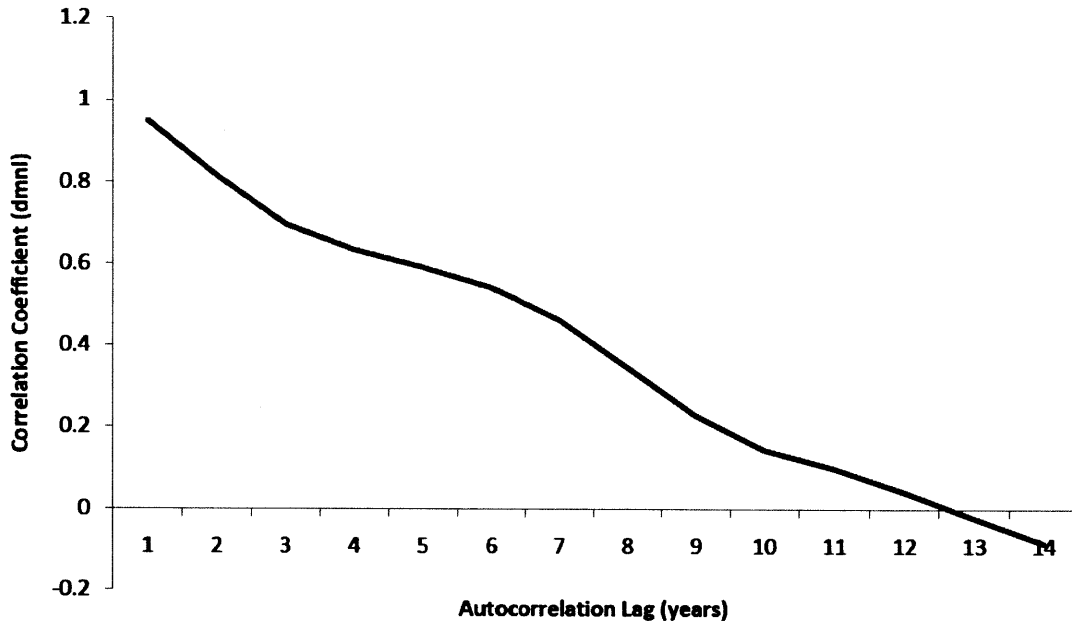
De-trended<sup>32</sup> nominal GDP shows significant autocorrelation. Following the process outlined by Oliva and Sterman (2001) I estimated the autocorrelation time of the pink noise in nominal GDP by computing the autocorrelation spectrum of the residuals from the trend removal procedure.

Figure 3-7 shows the autocorrelation spectrum of the residuals from the de-trending procedure. The decrease in the autocorrelation falls roughly linearly with the lag, consistent with the evidence that GDP often displays first-order  $1/f$  noise over long time horizons<sup>33</sup>. To see why the linear decline in autocorrelation implies first-order noise consider first that by the Wiener-Khinchin theorem, the power spectral density of a random process is the Fourier transform of its autocorrelation function. Over the domain we are interested in, the autocorrelation spectrum is well approximated by a triangle function. Since the Fourier transform of a triangle is the sinc

<sup>32</sup>The trend referenced was a best fit exponential curve of the quarterly nominal GDP recorded from 1989 through 2009.

<sup>33</sup>See Baillie (1996)

## GDP Residual Autocorrelation Spectrum



**Figure 3-7:** Autocorrelation Spectrum of the Residuals from De-trended Nominal GDP.

function squared, it follows that:

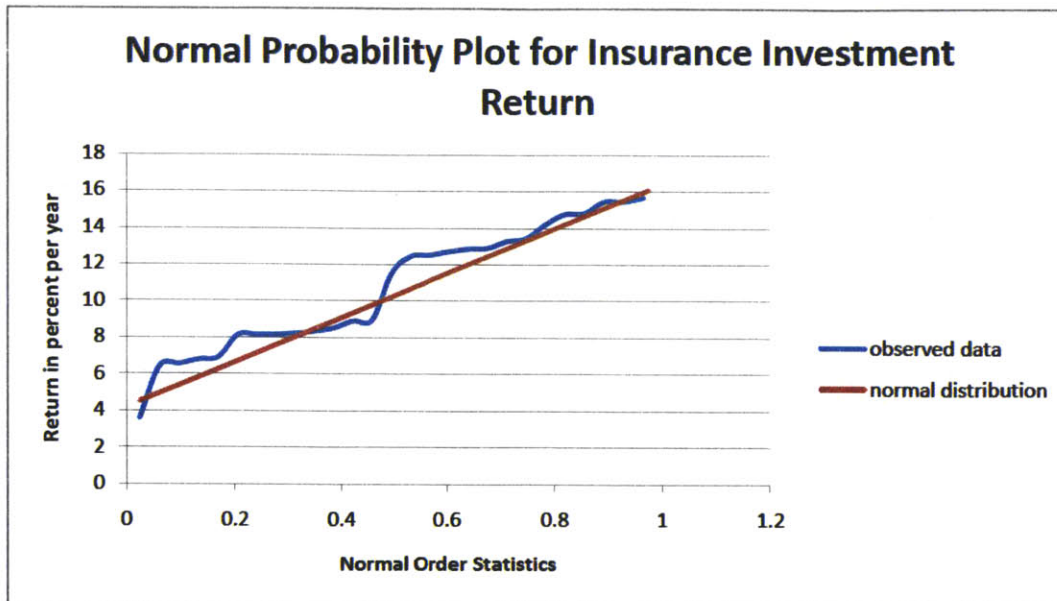
$$\ln(\text{Spectral Density}) \cong \ln\left(\frac{\sin(\lambda)}{\lambda}\right)^2 = 2 [\ln(\sin(\lambda)) - \ln(\lambda)] \quad (3.34)$$

When the result of equation 3.34 is plotted against  $\ln(\lambda)$  it is linear for large  $\lambda$  because  $\sin(\lambda)$  is bounded, showing that the spectrum of the noise in de-trended nominal GDP is approximately first order<sup>34</sup>. Unreported tests show that the autocorrelation of the noise in the residuals is not statistically different from zero after nine years of lag. The model therefore uses nine years as the noise correlation time in the pink noise generator function<sup>35</sup>. I also calculated the standard deviation of the residuals from the de-trending procedure to be four percent of the mean of the time series, and use this value as the GDP noise standard deviation in my model. The fitting process for de-trending nominal GDP showed an average of 3.7% growth per year, so stochastic GDP is modeled in my simulations as an exponential growth path at 3.7% per year multiplied by the output of the pink noise generator<sup>36</sup>.

<sup>34</sup>One definition of first order $1/f$  noise is that it has a power spectral density function that falls linearly with frequency on a log-log plot.

<sup>35</sup>Sterman 2000 Appendix B-2

<sup>36</sup>This simple formulation for GDP is a good tradeoff between complexity and realism. Because the stochastic flow of DP is only used for long horizon tests of the correlation between the model and random inflows the slower oscillation around the growth path for nominal GDP that is caused by business cycles and inflation was excluded from this analysis.



**Figure 3-8:** The normal probability plot of investment returns to the insurance industry is shown in this figure. The observed data depart from a normal distribution by tending to show negative skew, and a discontinuous probability density function that has a component with low variance (slope) and a separate component with high variance (slope).

### 3.6.2 Investment Returns

I created a historical time series of annual investment percentage returns for the insurance industry by dividing the total invested capital of firms in SIC 6331 by the sum of the reported investment income. Unreported regression tests to model the time series of investment returns for the insurance industry showed that distribution is highly correlated with the yield from corporate Baa rated bonds, however even when considering a diverse set of other financial instruments<sup>37</sup> the negative skew and the high variance of the distribution of returns for the insurance industry could not be matched by a linear model alone. Because of this, I model investment returns by adopting an analysis that Webster et. al (2007) use for modeling ozone emissions near Houston. In that study the authors break the observed output of the stochastic process into several distinct patterns of behavior, each hypothesized to be driven by a separate probability density function.

The normal probability plot of the data for insurance industry investment return shown in figure 3-8 exhibits several interesting characteristics. First, the observations form a function that tends to be concave, which along with the negative skewness calculated from the data suggest a left skewed probability density function, even when factoring in the non zero mean of the data. Second, a visual inspection of the plot suggests that there are two distinct patterns of behavior for investment return

<sup>37</sup>Aaa rated bonds, returns on the S&P 500, treasury notes and fixed maturity treasury bonds, as well as the interest rate carry were all tested as candidates for the linear ARIMA model.

<b>Low Variance Regime</b>	<i>Section 1</i>	<i>Section 2</i>	<i>Estimated <math>\sigma</math></i>	<i>Transition to High Chance</i>
Slope	9.15	6.79	2.82	22.73%
Intercept	6.66	5.85		
<b>High Variance Regime</b>	<i>Section 1</i>	<i>Section 2</i>	<i>Estimated <math>\sigma</math></i>	<i>Transition to Low Chance</i>
Slope	47.99	47.15	6.90	83.33%
Intercept	-14.54	1.46		
<b>Vasicek Model Parameters</b>	<i>Estimate</i>	<i>Dimensions</i>		
Tau - Adj. Delay	1	year		
b - Average	10.44%	%/year		

**Table 3.3:** The estimates obtained from the analysis of investment returns to the insurance industry show two clear regions of behavior. The figure also summarizes the transition probabilities for the Markov process modeled and the parameters used in the Vasicek model for investment returns.

volatility<sup>38</sup>. One pattern has relatively low variance while the other has relatively high variance but does not persist for a long period of time. Specifically, I computed linear estimates for different segments of the plot. These estimates suggest that investment returns can be modeled as a random normal process that switches between a standard deviation of 2.8% and a standard deviation of 6.9%. The low variance regime transitions to high variance roughly 23% of the time that it is active, and the high variance regime transitions back to low variance 83% of the time that it is active. The details of these estimations are shown in table 3.3.

Because an implementation of a stochastic process identical in form to the one employed by Webster et al. (2007) would require six separate probability density functions, and because economists have developed many models of the evolution of interest rate levels, I have chosen to use the technique described above to estimate only the variance of the distribution and the likelihood of transition between the two variance levels. In order to model the mean of the stochastic process for investment returns I turn to the one-factor, short-rate Vasicek model (James and Webber 2000). This model is described by the following equation:

$$\frac{dr}{dt} = \frac{(b - r)}{\tau} dt + \sigma dW_t \quad (3.35)$$

Where  $r$  is the interest rate,  $b$  is the long term mean of the process generating interest rates,  $\tau$  is the mean reversion time of the process<sup>39</sup>,  $\sigma$  is the standard deviation<sup>40</sup>, and  $dW_t$  is a Wiener-type white noise process<sup>41</sup>. This model formulation is

<sup>38</sup>The indication of the number of random normal processes needed to model the data comes from the number of best fit lines needed to estimate the plotted relationship. I depart from Webster et al. 2007 here in that I do not model the evolution of the mean of the stochastic process through a probability density function, but rather implement the Vasicek short-rate model, as discussed later.

<sup>39</sup>Or the adjustment delay of the negative feedback loop, in system dynamics terminology.

<sup>40</sup>Itself a random variable in my implementation, and modeled as a Markov process

<sup>41</sup>"Brownian Motion", implemented in discrete time as  $N(0,1)/\text{SQRT}(dt)$  where  $dt$  is the time step and  $N$  is a normal distribution with mean 0 and standard deviation of 1.



	$\mu$	$\sigma$	$U_c$	$U_s$	$U_m$
Modeled Random Process	.1076	.033	0.89	0.08	0.03
Historical Investment Return	.105	.036	-	-	-
Percentage Difference	2.5%	-9.3%			

**Table 3.4:** Statistical measures of fit between the historical investment returns and my stochastic formulation for returns are shown above. The values given for the modeled random process are the average of five hundred model runs from a test that varied the random noise seed of returns.

very similar to the “pink-noise” generator that is standard in the system dynamics literature. I justify my decision to deviate from the standard partly so that I can make a connection between the two approaches, and partly to highlight how I incorporate the Markov process for the variance of the investment returns over time. I use the term Markov to describe the fact that the standard deviation of returns can inhabit one of two discrete states, and that the transitions between these states occur based on a draw from a uniform random variable. In the model the current “state” of the variance of investment returns is a stock whose net flow is determined by a comparison of a uniform random variable and a cutoff level for state transition that is dependent the current state. The details of this formulation can be found in the appendix.

Overall this formulation for investment returns has statistical behavior that is close to the historical time series. Table 3.4 shows the statistics of fit to substantiate that claim. On average, stochastic returns have a standard deviation within 0.04 of the observed standard deviation, and a mean within 0.003 of that observed. Ninety-five percent of the five hundred simulations in this sensitivity analysis showed that at least three quarters of the error between the simulated and actual data was due to differences in their covariance, rather than their mean or variance<sup>42</sup>, and the average Theil  $U_c$  over the entire set of simulations was nearly 0.9.

## 3.7 Endogenous Model Parametrization

### 3.7.1 Parameters Estimated and their Interpretation

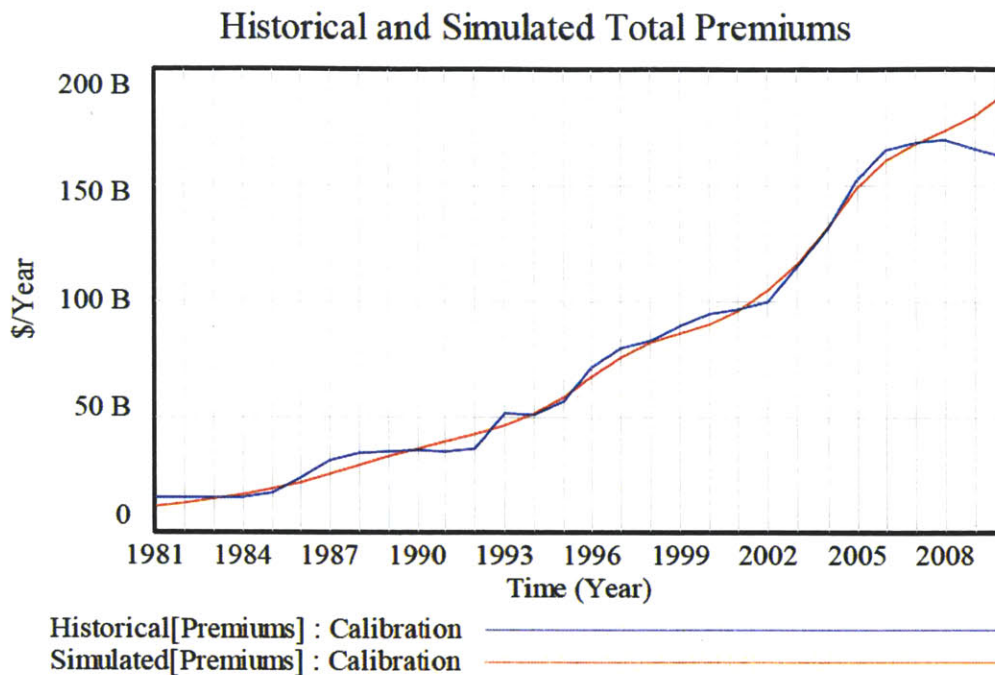
Table 3.5 documents the parameters estimated by my calibration of the model. I arrived at these estimates through a multi-dimensional minimization of the root mean square error (RMSE) scaled by the variance of each historical data series, using the Davidon–Fletcher–Powell method. Explicitly, the objective function of the calibration process was:

$$\text{Minimize} \left\{ \left[ \frac{(PrInc_H - PrInc_t)}{\sigma_{HP_r}^2} \right]^2 + \left[ \frac{(C_H - C_t)}{\sigma_{HC}^2} \right]^2 + \left[ \frac{(NI_H - NI_t)}{\sigma_{HNI}^2} \right]^2 \right\} \quad (3.36)$$

<sup>42</sup>i.e. 95% of the 500 simulations had a Theil inequality statistic  $U_c$  greater than 0.75.

Calibrated Model Parameters	Lower Bound	Estimate	Upper Bound
Average Delay for Claim Investigation ( <i>years</i> )	1.499	2.678	4.6
Claim Handling Costs per Dollar of Claims ( <i>dmnl</i> )	0.01	0.036	0.12
Commission per Dollar of Premium Written ( <i>years</i> )	0.148	0.25	0.29
Critical Claims Solvency Ratio ( <i>years</i> )	0.799	1	1.788
Desired Insurance Adjustment Time ( <i>years</i> )	2.352	5.11	9.181
Dividend Payout Ratio ( <i>dmnl</i> )	0	0.11	0.442
Income Elasticity of Demand ( <i>dmnl</i> )	0.436	0.453	0.465
Insurable Life of Capital ( <i>years</i> )	8.149	14	16.37
Natural Casualty Rate ( $\frac{dmnl}{year}$ )	0.048	0.06	0.067
Normal Fraction of Assets Desiring Insurance ( <i>dmnl</i> )	0.031	0.041	0.041
Other Cost per Dollar of Exposure ( $\frac{dmnl}{year}$ )	0.002	0.015	0.019
Price Elasticity of Demand ( <i>dmnl</i> )	-2.3	-1.5	-0.908
Sensitivity of Expected Casualty Rate to Scope ( <i>dmnl</i> )	0.4	1	3.48
Sensitivity of Premiums to Capital ( <i>dmnl</i> )	-0.106	-0.088	-0.086
Sensitivity of Premiums to Net Income ( <i>dmnl</i> )	-1.275	-1.03	-0.743
Sensitivity of Scope to Capital ( <i>dmnl</i> )	0	0.2	0.472
Sensitivity of Scope to Income ( <i>dmnl</i> )	0	0.2	3.985
Time Horizon for Reference Costs ( <i>years</i> )	1.4	3.2	6.7
Time to Adjust Net Income Perception ( <i>years</i> )	1.18	2	2.03
Time to Change Dividend Policy ( <i>years</i> )	1.282	4.5	5.36
Time to Change Insurance Scope( <i>years</i> )	0.62	1.2	1.795
Time to Change Premiums ( <i>years</i> )	0.2	0.56	1.7
Time to Pay Commissions ( <i>years</i> )	0.23	0.35	0.512
Time to Perceive Trend in Costs ( <i>years</i> )	0.72	0.9	2.3

**Table 3.5:** The parameters estimated during my calibration of the insurance model to historical data. The units of each parameter are shown next to its name, with *dmnl* used interchangeably with dimensionless, fraction and percent. The 95% confidence intervals employ the non-parametric bootstrap procedure of Dogan (2007) with N=1000.



**Figure 3-9:** A comparison of the historical path for premiums and the simulated path in the model. The model fits the historical data well, and captures important cyclical dynamics.

This combines the work of Sterman (1984) with the technique of trading-off between dimensions when fitting large models by weighting more variable series less than ones with lower variance that is used by weighted least squares estimation.

In order to calculate the 95% confidence intervals reported in the table I follow the process outlined by Dogan (2007). Specifically, I use the residual between the simulated and historical output of the model to create one thousand bootstrapped<sup>43</sup> data sets, and re-parametrize the model for each of these data sets starting from my original parameter estimates. The output of that process is a sample (N=1000) of the possible values for each of the parameters, when the largest and smallest 2.5% of the sample are excluded for each parameter the remaining maximum and minimum estimates form the confidence interval bounds.

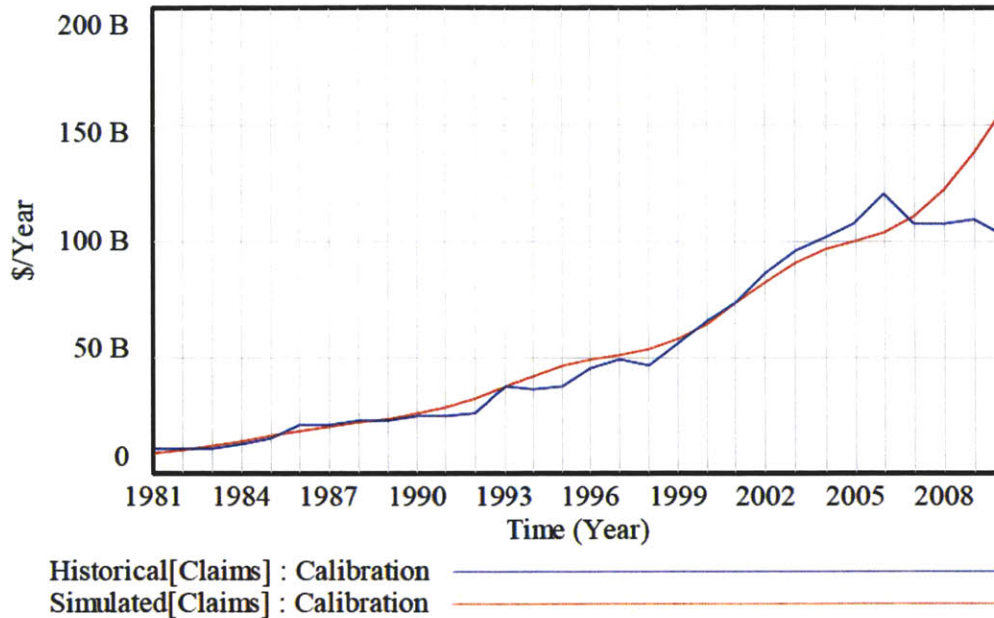
### 3.7.2 Model Fit to Historical Data

The fit of simulated premiums with historical premiums is shown in figure 3-9. Overall the model does a good job of tracking the path of premiums collected by the industry. The Theil U statistics for the simulation show that over 91% of the estimation error in premiums is due to random fluctuations<sup>44</sup> rather than differences between the mean

<sup>43</sup>The bootstrap sampling is non-parametric.

<sup>44</sup> $U_c=0.919$

### Historical and Simulated Claims Incurred



**Figure 3-10:** The simulated path of total claims incurred in the model, plotted with the historical path of claims incurred.

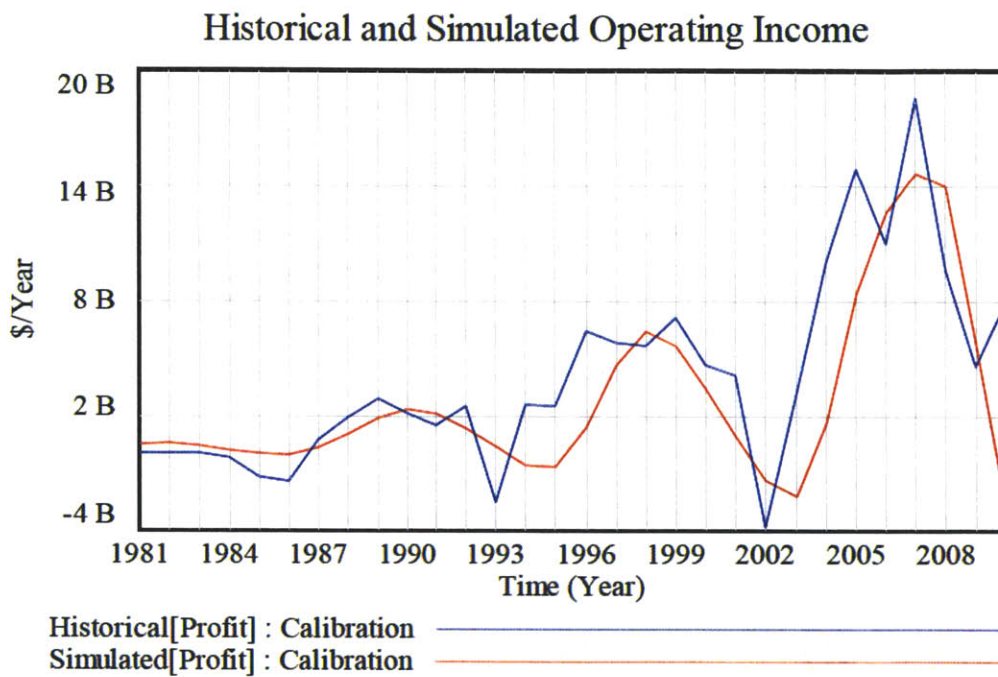
or variance of the two time series. The RMSE of the simulation scaled by the mean of the historical data series is 5.62% at the end of the model run.

The simulated path for claims, compared with the historical data, is shown in figure 3-10. The simulation fits the growth of claims in the industry fairly well, and very closely estimates the variance<sup>45</sup>. The RMSE of the simulated claims, scaled by the historical mean, provides some reason to be confident in the models output, at 15%.

The fit of the model to historical profits is shown in figure 3-11. Visual inspection of the simulated course of profits for the insurance industry, shown in figure 3-11, shows a regular cycle in reported profit for the simulated industry, with a cycle period of very close to the 6-7 years measured from the historical data. The evolution of profits in the model is statistically similar to the historical path history. In particular, the simulated series for profit shows a 67.5%  $R^2$  with actual profit through 2008<sup>46</sup>, and has a Theil statistic  $U_c$  of 86.1% which indicates that relatively little of the estimation error for profit comes from a misrepresentation of its mean or variance.

<sup>45</sup>Theil  $U_m=0.045$   $U_s=0.008$

<sup>46</sup> $R^2$  is an appropriate metric to use for profits, as the time series has a high variance relative to its mean. The  $R^2$  for claims and premiums are very high, but this is a mechanical result of their exponential growth paths. On the other hand, RMSE over the mean of profits would artificially inflate our perception of the error, since the mean of profits is very low over the length of the model run. Sterman (1984)



**Figure 3-11:** The simulated path of insurance industry profits plotted with the historically observed path of profits. Many of the features of the historical path are emulated by the model.

SIC 6331 Variable	$R^2$	Slope	t-stat
Assets	0.797	0.093	10.098
Claims paid	0.940	0.091	20.128
Dividends	0.049	0.049	0.112
Invested capital	0.553	0.043	5.668
Investment income	0.417	0.046	4.309
Total Liabilities	0.942	0.055	20.566
Stockholders equity	0.688	0.041	7.568
Commissions expense	0.822	0.080	10.956
Total Expense	0.946	0.077	21.345

Used in Calibration	$\frac{RMSE}{\mu}$	$U_m$	$U_s$	$U_c$	$R^2$
Operating Income	0.772	0.095	0.044	0.861	0.675
Premiums Collected	0.056	0.005	0.076	0.919	0.994
Claims Incurred	0.150	0.045	0.008	0.947	0.957

**Table 3.6:** Statistics of fit for the insurance model are shown in the table above. The first set of variables is not available at the level of aggregation needed to undertake point by point estimates, therefore I report regression slopes, t-statistics and  $R^2$ . The second set of variables reports the root mean square error over the mean, the Theil U statistics of fit and the  $R^2$ .

### 3.7.3 Comparison with Other Data Series

There is a considerable amount of publicly available financial data on the insurance industry as a whole, however the types of data that are reported by the SEC specifically for the “non-life” insurance industry are more limited. The model calibration procedure was run using only the time series that were both important and reported separately from the aggregate, namely the total premium income, total claims incurred and operating income.

The rest of the available data still has the potential to be of use in evaluating the model’s fit, if reasonable assumptions are made about the relationship between the reported data and the concepts embodied in my model’s formulations. Table 3.1 from section 3.3 reports each of the data series I used during this modeling effort, as well as their level of aggregation with respect to the property casualty insurance industry. Table 3.6 reports the statistics of fit between my model’s output and all of the data series I employed. For SIC 6331 variables these tests assume that the unobservable time series for the property casualty insurance industry are correlated with the data for the overall insurance industry, but are not point for point matches. Regression slope statistics are reported, with standard errors,  $R^2$  and t-statistics, as a test of this assumption. Each of these regressions is of the form  $Sim = \alpha + \beta \cdot Hist + \varepsilon$  where  $Sim$  is the simulated data and  $Hist$  is the historical data over the time period from 1982 through 2010.

Overall The simulated variables, excepting only dividends, show a high correlation with their historical time series, have statistically significant regression slope estimates, and are all on the same order of magnitude.

## 3.8 Stochastic Tests of Model Fit

In settings such as the insurance industry, where random variations in exogenous variables are widely held to have a large effect on the time series of data available<sup>47</sup>, a comparison of the correlations between variables can help to validate the causal relationships in the model, since random exogenous influences are more likely to effect the value of the variables than their long term relationships between each other. Additionally, such an analysis allows us to better understand how the exogenous forcing in my model of the insurance industry compares to the effect of exogenous variables in the historical data series.

Table 3.7 shows the correlation matrices from a series of tests on historical and simulated model data. The first matrix shows the Pearson correlation coefficients between the historically observed data series over the period from 1982 until 2009. The second matrix shows the same set of correlations calculated from the simulated data, but instead of only running the model from 1982 until 2009 I use the stochastic random variables for nominal gross domestic product and investment return described in section 3.6 to drive the model over a long time horizon. The correlations documented are for one thousand years of simulated data using these exogenous inputs. The final matrix in table 3.7 records the difference between the historically observed correlations and the simulated ones, and reveals several insights on the relationship between the historical variables and my simulation.

First, the correlations suggest that many of the relationships in my model closely capture the statistical comovement between insurance industry variables. In fact the only variable that shows a consistent difference between the simulated correlation coefficients and the historically observed ones, is dividends.

The evidence from table 3.7 suggests that my parsimonious formulation of dividends in the model may overestimate the degree to which dividends issued by insurers correlate with important financial data. Future modelers in this space should potentially consider more complex formulations for insurance dividends, however I chose to leave the simpler formulation in my model. The overall effect of this decision is minor, because the variable I am most interested in is income, which excludes dividends, and in my estimation the face-validity benefits from expressing a feedback-rich formulation for dividends are easily outweighed by the costs of a marginally poorer model fit.

## 3.9 Examination of the Cause of the Insurance Profit Cycle

One of the research questions left unsettled in the literature on the insurance profit cycle is whether the cycle owes its cause primarily to the endogenous feedback processes created by the decision rules of the industry's actors, or whether fluctuations in

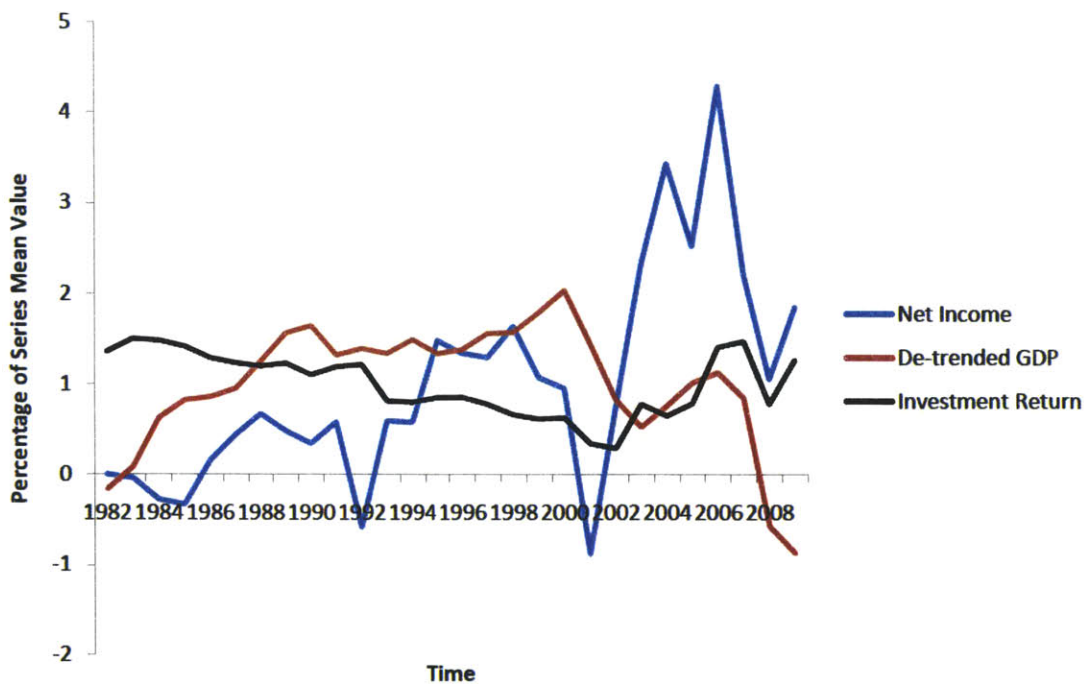
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<sup>47</sup>See section 3.2 for a discussion of the role of exogenous time series in prior research on the insurance industry.

Historical	TA	CI	CE	DIV	Cap	Inv	TL	Inc	P	SE	Com	TE	GDP
TA	1												
CI	0.98	1											
CE	0.96	0.97	1										
DIV	0.47	0.46	0.50	1									
Cap	0.94	0.97	0.90	0.40	1								
Inv	0.91	0.86	0.83	0.52	0.82	1							
TL	1.00	0.99	0.96	0.43	0.95	0.89	1						
Inc	0.74	0.70	0.68	0.23	0.69	0.81	0.72	1					
P	0.99	0.98	0.98	0.50	0.92	0.90	0.98	0.77	1				
SE	0.98	0.96	0.96	0.56	0.90	0.93	0.97	0.76	0.98	1			
Com	0.93	0.96	0.96	0.39	0.93	0.74	0.95	0.61	0.93	0.90	1		
TE	0.98	0.99	0.98	0.48	0.95	0.87	0.98	0.72	0.99	0.97	0.95	1	
GDP	0.98	0.97	0.99	0.53	0.90	0.87	0.97	0.70	0.99	0.98	0.93	0.98	1
Simulated	TA	CI	CE	DIV	Cap	Inv	TL	Inc	P	SE	Com	TE	GDP
TA	1												
CI	0.99	1											
CE	0.99	1.00	1										
DIV	0.83	0.83	0.84	1									
Cap	1.00	0.99	0.99	0.83	1								
Inv	0.88	0.89	0.89	0.78	0.88	1							
TL	0.99	1.00	1.00	0.85	0.99	0.88	1						
Inc	0.78	0.75	0.77	0.95	0.78	0.70	0.78	1					
P	0.99	1.00	1.00	0.85	0.99	0.88	1.00	0.78	1				
SE	1.00	0.98	0.98	0.82	1.00	0.88	0.98	0.78	0.98	1			
Com	0.99	1.00	1.00	0.85	0.99	0.88	1.00	0.78	1.00	0.98	1		
TE	0.99	1.00	1.00	0.84	0.99	0.89	1.00	0.77	1.00	0.98	1.00	1	
GDP	0.99	0.98	0.99	0.83	0.99	0.85	0.98	0.76	0.98	0.98	0.98	0.98	1
Difference	TA	CI	CE	DIV	Cap	Inv	TL	Inc	P	SE	Com	TE	GDP
TA	0												
CI	0.01	0											
CE	0.03	0.02	0										
DIV	0.37	0.37	0.34	0									
Cap	0.06	0.02	0.09	0.43	0								
Inv	-0.03	0.03	0.06	0.27	0.06	0							
TL	0.00	0.01	0.04	0.42	0.04	-0.01	0						
Inc	0.04	0.05	0.10	0.71	0.09	-0.11	0.06	0					
P	0.01	0.02	0.02	0.35	0.07	-0.02	0.02	0.02	0				
SE	0.01	0.03	0.03	0.27	0.10	-0.05	0.01	0.01	0.00	0			
Com	0.06	0.04	0.04	0.46	0.06	0.14	0.05	0.17	0.07	0.08	0		
TE	0.01	0.00	0.02	0.36	0.04	0.01	0.02	0.05	0.01	0.02	0.05	0	
GDP	0.01	0.01	0.00	0.30	0.09	-0.01	0.01	0.05	0.00	0.00	0.05	0.00	0

**Table 3.7:** This figure shows the correlation matrices for the data obtained historically and the data simulated, as well as the difference in measured correlation between the two sets. The first matrix shows the correlations between the historical data from 1982 until 2009. The second matrix shows the correlation between simulated variables driven by stochastic exogenous inputs when simulated for 1000 years. The final matrix shows the difference in the two sets of correlations calculated as (*Simulated – Historical*). *TA* is total assets, *CI* is claims incurred, *CE* is claims expense, *DIV* is total dividends, *Cap* is investment capital, *Inv* is investment income, *TL* is total liabilities, *Inc* is income, *P* is total premiums, *SE* is shareholders equity, *Com* is commissions expense, *TE* is total expenses and *GDP* is nominal gross domestic product.





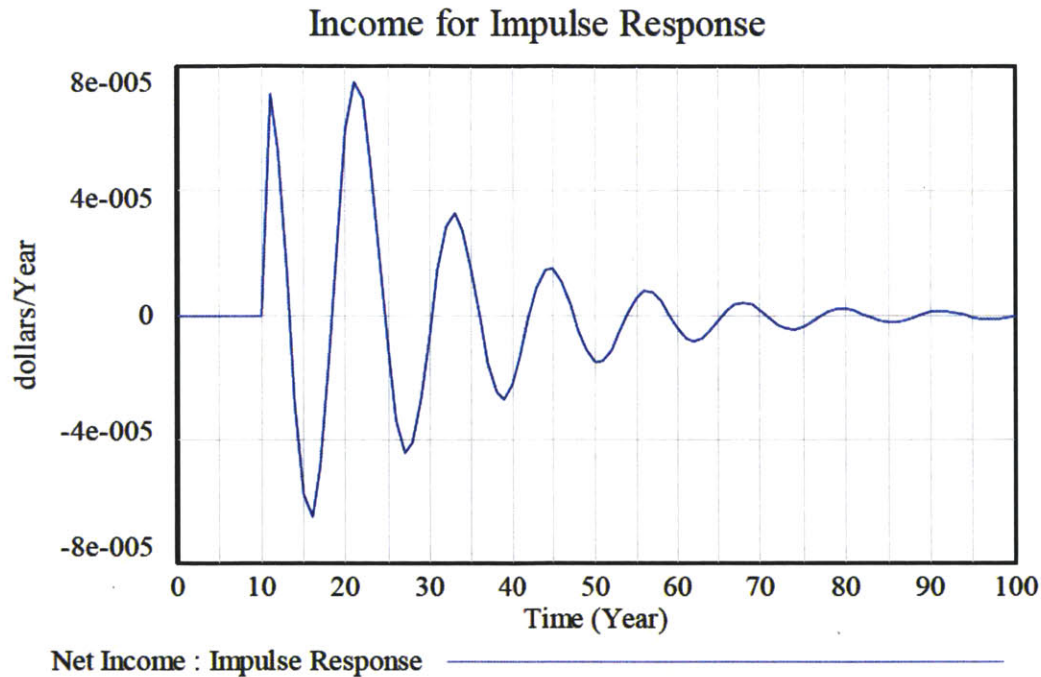
**Figure 3-12:** Net Income and Exogenous Influences, plotted against time as percentages of their mean values. GDP is de-trended nominal GDP and investment return is the percentage return on total invested assets.

exogenous inputs are primarily to blame. The following subsections will attempt to address this question through several tests that use both my model and the exogenous data available.

### 3.9.1 Exogenous Influences on the Insurance Industry

Figure 3-12 shows the major exogenous influences on the insurance industry plotted against time, as well as the aggregate net income for “non-life” insurance reported to the SEC.

Visual inspection of the figure does not reveal an obvious correlation between GDP and the net income of the insurance industry, though in 2001 and in 2009 dips in net income occur contemporaneously with falling GDP. Argument by example yields conflicting evidence however, as the drop in profitability in the early 1980’s occurs contemporaneously with rising GDP, and the drop in GDP in the early 1990’s is not nearly as large as the drop in the late 1990’s yet both coincide with sizable drops in insurance operating income. Basic statistical analysis of the time series also reveal little of interest, as correlations between the exogenous time series and insurer profits are negative and not statistically significant, with the correlation coefficient between insurance net income investment return measured to be -0.109, and the coefficient between GDP and insurance net income calculated to be -0.068.



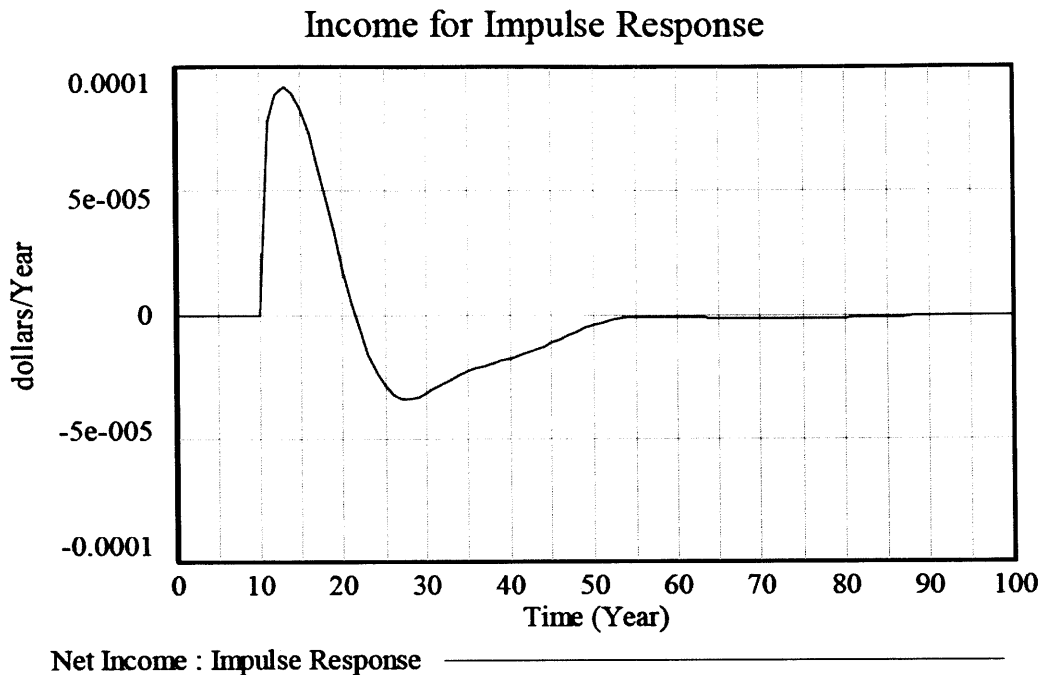
**Figure 3-13:** This figure shows the response of net income to a momentary increase in GDP during the simulated year 10. The impulse response of net income displays a clear cyclical mode, with a period very close to the one observed historically.

### 3.9.2 Test of the Model’s Impulse Response

Because an examination of the exogenous inputs do not allow us to make definitive conclusions about their role in the cycle, I built the model with the capability of starting it in dynamic equilibrium. Starting from that state, I shock the model with a momentary increase in GDP to test how income responds. When the exogenous forcing of historical GDP in the model is removed and investment income is set to a constant fraction, the model is shocked from equilibrium by a discrete time Dirac delta function at the beginning of year 10. GDP immediately returns to its initial level after this “pulse.” The response of net income, shown in figure 3-13, provides strong evidence for an endogenous source of the insurance profit cycle.

Figure 3-13 presents compelling evidence that the structure that generates net income in the insurance industry adds cyclical component to signals from exogenous influences such as GDP. Even though GDP is very important for the evolution of profits in the insurance industry, the impulse response of my model indicates that profit cycles in insurance would persist for many years even if the economy were somehow brought into equilibrium.

The oscillation in figure 3-13 is not attenuated by changes to many of the parameters in the model. In fact, my analysis of the system’s impulse response revealed only one policy that was successful in causing the impulse response of profit to stabilize, as



**Figure 3-14:** When capital targets are much higher than estimated by my historical calibration of the model, and the adequacy of capital is a much stronger input into the scope expansion decisions of the industry, the impulse response shown in this figure results. This combined policy was by far the most effective at damping the cycle produced by my model.

shown in figure 3-14. Interestingly this policy way inherently multivariate in nature. Not only do capital requirements need to be increased, through increasing the critical solvency ratio, but the importance of capital adequacy in the decisions controlling premium setting and scope needs to be considerably larger than was estimated during my model calibration. If only capital requirements are changed, the period of the oscillations enlarges, but the damping is negligible. If capital is made a more important input for decisions, but targets for the level of capital are held constant the system's impulse response is actually made less stable by the change.

This type of test is one of the many benefits of feedback rich dynamic models. Not only can they replicate historical data, but they can provide us with more general information about the effect of the structures we are interested in. On the one hand, my analysis in this section provides support for the hypothesis that insurance profit cycles are driven by the characteristics of the industry rather than the idiosyncratic path of the exogenous inputs to the industry. In addition however, the impulse response tests indicate that profit cycle severity may be reduced more fully when changes to the target level of capital are combined with increases in the importance of capital in decision making. In the next section I will explore how the historical path of profits might have been altered had policies informed by these insights been implemented.

	$\sigma/\mu$	$\Delta\%$
Base-model scaled profit variability	1.47	N/A
<b>Univariate Tests</b>		
Premiums Reactive to Capital	1.45	-2%
Scope Reactive to Capital	2.78	89%
Higher Reserve Target	1.18	-20%
<b>Multivariate Tests</b>		
Target and Premiums	0.91	-38%
Target and Scope	1.59	8%
All Three Policies	0.83	-44%

**Table 3.8:** The results for tests of several policies for mitigating the insurance industry profit cycle are shown in this table. The standard deviation of net income, scaled by its mean, is shown in the column labeled  $\sigma/\mu$  and is computed over the entire model run. “Premiums Reactive to Capital” sets the importance of capital adequacy signals for premium setting equal to the importance of profit signals. “Scope Reactive to Capital” increases the importance of capital adequacy in the scope setting decision. “Higher Reserve Targets” simulates a situation where reserve requirements are increased such that insurers now desire twice the level reserves. Multivariate tests combine the indicated policies. Overall, policies that focus on both higher and more salient reserves result in the largest decrease in the severity of the profit cycle.

### 3.10 Policies for Reducing the Cycle in Insurance Industry Profits

Informed by the analysis of the impulse response of the model, sensitivity tests of both the univariate and the multivariate effect of several policy levers on the scaled profit variability<sup>48</sup>, described in table 3.8, show that policies that combine higher reserve targets with an increase in the importance of capital in determining the path of the industry are the most effective at reducing the cycle. Higher reserve requirements alone do reduce cycle severity somewhat. When these requirements are combined with an increased willingness of decision makers in the industry to use capital adequacy in their premium and scope setting decisions however, profit stability is increased considerably more.

This result presents an interesting case for the implementation of reserve requirements by regulators. If industry actors view increased requirements as cumbersome or punitive they may continue to regard short-term profit signals as the more important measure of the financial health of their companies. If this happens, the model indicates that the full effect of capital for creating aggregate profit stability will not

<sup>48</sup>When testing policies for mitigating the profit cycle in the insurance industry I use a ratio of the standard deviation of profit to the mean of profit as my primary statistical focus. This ratio, which I call the scaled profit variability, is a good summary measure of the intensity of the profit cycle in an industry because it captures how variable profits are without improperly labeling high average profits as unappealing simply because of their mechanically higher standard deviation. The variance scaled by the mean would be equally appealing, but is functionally equivalent.

be felt. On the other hand, if the insurance industry views higher capital targets as not only required, but inherently important for competitive decisions, then the model suggests that the profit cycle can be reduced considerably.

### 3.11 Conclusion

This essay focused primarily on the documentation of a profit cycle model in the property casualty insurance industry, a setting without a significant delay for adjusting productive capacity. Tests of the model's output presented evidence that the key determinants of the severity of the profit cycles in the industry are the level of capital and the salience of capital adequacy signals in decision making.

Section 3.9 presented evidence that the cycle in profits of the insurance industry is endogenously generated, rather than exogenously forced. The modeled industry responded to a delta function in GDP with a long-lasting cyclical oscillation. The cyclical nature of the model's impulse response can only be eliminated when capital targets are combined with an increased importance of capital in decision making, adding evidence that policies that do not address the high salience of insurer profit signals may not fully address the cause of profit cycles in the insurance industry.

When viewed together with the results of chapter two's analysis of airline industry profit cycles, these results begin to point towards the salience of profit signals as a dynamic that exacerbates profit cycles across diverse settings. Two data points is certainly not a large enough sample to draw conclusions, however, both airlines and property-casualty insurance are industries with highly commodified products and significant delays in adjusting their cost structure to changing market environments. The suggestion that the cyclical profit common to both can be significantly reduced through policies that mitigate the intensity competition over short term profits is a potentially promising area for further research, challenging the belief that market forces exclusively increase profit.

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# Appendix A

## Documentation of the Airline Industry Model

### A.1 Load Factor and Capacity

#### A.1.1 Airline Capacity (Seat)

$$= \int (\text{AirplaneManufacturingCompletion} + \text{OffMothballing} - \text{AirplaneRetirements} - \text{Mothballing}) dt + [\text{InitialAirlineCapacity}]$$

Description: This is the number of seat miles per quarter that can be flown by the airline

#### Airplane Manufacturing Completion (Seat/Year)

$$= \text{AirlineCapacitySupplyLine} / \text{TimeRequiredtoManufactureanAirplane} * \text{SwitchforPartialModelTests} + \text{Completion} * (1 - \text{SwitchforPartialModelTests})$$

Description: This is the completion rate for aircraft that are coming off of the assembly line

Airline Capacity Supply Line is a stock that is covered in A.1.2

#### Time Required to Manufacture an Airplane (years) 2

Description: This is the average lag before aircraft orders are delivered

#### Switch for Partial Model Tests (dmnl) 0

#### Completion (Seat/Year)

$$= \text{CapacityonOrder3} / (\text{TimeRequiredtoManufactureanAirplane} / 3)$$

Description: This is the flow of completed aircraft

Capacity on Order 3 is a flow covered in A.2.7

**Time Required to Manufacture an Airplane is covered in A.1.1**

**Off Mothballing (seats/Year)**

= ReturntoService

Description: The flow of planes off mothballing

**Return to Service (seats/Year) is a variable covered in A.2.3**

**Airplane Retirements (Seat/Year)**

=Retired\*(1-SwitchforPartialModelTests)+(AirlineCapacity/  
AverageServiceLife)\*SwitchforPartialModelTests

Description: This is the rate at which airplanes are retired from the fleet

**Retired is a variable covered in A.2.3**

**Switch for Partial Model Tests is a variable covered in A.1.1**

**Airline Capacity is a variable covered in A.1.1**

**Average Service Life 30**

Description: The average life of an airplane is approximately 30 years

**Mothballing (seats/Year)**

= IntoStorage

Description: the flow of planes into mothballing

**Into Storage is a variable covered in A.2.3**

**Initial Airline Capacity (Seat)**

=HistoricalAirlineDemand/NumberofMilesFlownperSeat/  
NormalLoadFactor\*(1-SwitchforPartialModelTests)  
+InitialCapacityforPartialModelTest\*SwitchforPartialModelTests

Description: This is the initial capacity of seat miles per quarter

**Historical Airline Demand is a variable covered in A.5.2**

**Number of Miles Flown per Seat is a variable covered in A.4.1**

**Normal Load Factor is a variable covered in A.4.3**

Switch for Partial Model Tests is a variable covered in A.1.1

Initial Capacity for Partial Model Test is a variable covered in A.1.2

### A.1.2 Airline Capacity Supply Line (Seat)

$$= \int (\text{Orders of Airplanes} - \text{Airplane Manufacturing Completion} - \text{Cancellation}) dt + [\text{Initial Capacity on Order}]$$

Description: This is the capacity on order at the airlines

#### Orders of Airplanes (Seat/Year)

$$= \text{Max}(\text{Indicated Capacity Adjustment} - \text{Return to Service}, 0)$$

Description: Airlines first reduce orders for new capacity by the amount of capacity returned to service from any mothballed fleet, then order what they need to replace retirements and adjust capacity to target levels. Orders are constrained to be nonnegative.

#### Indicated Capacity Adjustment (seats/Year)

$$= \text{Desired Capacity Acquisition Rate} + \text{Adjustment for the Supply Line} + \text{Supply Line Adjustment for Growth in Demand}$$

Description: The indicated order for seats for the industry is equal to the desired capacity acquisition rate plus an adjustment for the supply on order and a further adjustment for the expected growth rate of the industry

#### Desired Capacity Acquisition Rate (Seat/Year)

$$= \text{Planned Replacement Orders} + \text{Capacity Adjustment for Growth in Demand} + \text{Adjustment For Capacity}$$

Description: The desired rate of addition of new seats to the industry is their planned retirements plus an addition to correct for the gap between capacity and its desired level

- **Planned Replacement Orders (seats/Year)**

$$= \text{Airplane Retirements}$$

Description:

- Airplane Retirements is a variable covered in A.1.1

- **Capacity Adjustment for Growth in Demand (Seat/Year)**

$$= \text{Airline Capacity} * \text{Expected Growth Rate for Demand} * \text{Weight on Demand Forecast Orders}$$

Description: Decision makers must make sure to grow the total number of planes at the expected growth rate of demand if they are going to accommodate demand in the long run.

- Airline Capacity is a stock covered in A.1.1
- Expected Growth Rate for Demand is a stock covered in A.3.1
- Weight on Demand Forecast Orders (fraction)
  - \* 1
  - \* Description: this is the weight that the industry places on forward looking demand forecasts

- **Adjustment For Capacity (Seat/Year)**

$$= (\text{DesiredCapacity} - \text{AirlineCapacity}) / \text{Time to Adjust Capacity}$$

Description: This is the additional capacity desired based on the current demand, current capacity and the desired load factor

- Desired Capacity (Seat)
  - =  $\text{DesiredSeatMiles} / \text{NumberOfMilesFlownperSeat} * (1 - \text{SwitchforPartialModelTests}) + \text{InitialCapacityforPartialModelTest} * \text{Exp}(\text{ExpectedGrowthRateforDemand} * (\text{Time} - \text{INITIALTIME})) * \text{SwitchforPartialModelTests}$
  - \* Desired Seat Miles (Seat\*miles/Year)
    - =  $\text{EstimatedCurrentDemand} / \text{NormalLoadFactor}$
    - Description: This is the desired number of seat miles given the desired load factor
  - Estimated Current Demand (Seat\*miles/Year)
    - =  $\text{PerceivedDemand} * (1 + \text{ExpectedGrowthRateforDemand} * \text{Time to Perceive Changes in Demand})$
    - Description: The current perceived demand must first be projected into the future by the "Time to Perceive Changes in Demand" to get a projection of instantaneous demand. Then if demand forecasts are going to be added over a time horizon other than one year, the structure above allows the modeler to achieve this as well
- Perceived Demand is a variable covered in A.3.2
- Expected Growth Rate for Demand is a variable covered in A.3.1
- Time to Perceive Changes in Demand is a variable covered in A.3.2
- Normal Load Factor is a variable covered in A.4.3
- \* Number of Miles Flown per Seat is a variable covered in A.4.1
- \* Switch for Partial Model Tests is a variable covered in A.1.1
- \* Initial Capacity for Partial Model Test (seats)
  - 100
  - Description: The number of seats of capacity needs to be initialized for the partial model test so that we can see that the stock of capacity track the desired capacity without steady state error

- \* Expected GrowthRate for Demand is a variable covered in A.3.1
- Airline Capacity is a stock covered in A.1.1
- Time to Adjust Capacity (Year)
  - \* 0.594
  - \* Description: This is the horizon over which the capacity adjustment is evaluated

**Adjustment for the Supply Line (Seat/Year)**

$$= \text{Weight on Supply Line Adjustment} * (\text{Desired Aircraft Supply Line} - \text{Airline Capacity Supply Line}) / \text{Supply Line Adjustment Time}$$

Description: Aircraft ordering is adjusted for the gap between seats on order and the desired supply line

- Weight on Supply Line Adjustment

1

Description: Allows for the industry to weight future supply adjustments

- Desired Aircraft Supply Line (Seat)

$$= \text{Desired Capacity Acquisition Rate} * \text{Time Required to Manufacture an Airplane}$$

Description: In order to achieve the capacity acquisition rate given the delay in aircraft manufacture the industry needs this many seats on order

- Desired Capacity Acquisition Rate is a variable covered in A.1.2
- Time Required to Manufacture an Airplane is a variable covered in A.1.1

- Airline Capacity Supply Line is a variable covered in A.1.2

- Supply Line Adjustment Time (Year)

0.1

Description: Decisions to adjust the supply line are smoothed over this time period

**Supply Line Adjustment for Growth in Demand (Seat/Year)**

$$= \text{Weight on Demand Forecast Orders} * \text{Expected Growth Rate for Demand} * (\text{Airline Capacity Supply Line})$$

Description: Decision makers must make sure to grow the supply line of planes at the expected growth rate of demand if they are going to accommodate demand in the long run.

- Weight on Demand Forecast Orders is a variable covered in A.1.2
- Expected Growth Rate for Demand is a variable covered in A.3.1
- Airline Capacity Supply Line is a variable covered in A.1.2

**Return to Service is a flow covered in A.2.3**

**Airplane Manufacturing Completion is a flow covered in A.1.1**

**Initial Capacity on Order (Seat)**

$$= (\text{InitialAirlineCapacity} / \text{AverageServiceLife} + \text{InitialAirlineCapacity} \\ * \text{InitialExpectedGrowthRateinDemand} * \text{WeightonDemandForecastOrders}) \\ * \text{TimeRequiredtoManufactureanAirplane}$$

Description: The initial value of capacity on order to get the capacity to balance expected retirements

**Initial Airline Capacity is a variable covered in A.1.1**

**Average Service Life is a variable covered in A.1.1**

**Initial Expected Growth Rate in Demand is a variable covered in B.6.1**

**Weight on Demand Forecast Orders is a variable covered in A.1.2**

**Time Required to Manufacture an Airplane is a variable covered in A.1.1**

**Cancellation (seats/Year)**

$$= \text{CancelledOrders}$$

Description: This is the rate of airline order cancellations

**Cancelled Orders (seats/Year)**

$$= \text{IFTHENELSE}(\text{IndicatedCapacityAdjustment} < 0, \\ \text{Min}(-\text{IndicatedCapacityAdjustment}, \text{CapacityonOrder1} / \text{TimetoCancel}), 0)$$

Description: This is the rate of airline order cancellations

**Indicated Capacity Adjustment is a variable covered in A.1.2**

**Capacity on Order 1 is a variable covered in A.2.5**

**Time to Cancel (years)**

- 0.1
- Description: This time constant controls how quickly orders of airplanes can be canceled

**A.1.3 Mothballed Capacity (seats)**

$$= \int (\text{Mothballing} - \text{OffMothballing}) dt + [0]$$



**Mothballing is a flow covered in A.1.1**

**Off Mothballing is a flow covered in A.1.1**

Description: The stock of planes currently mothballed. This stock is equivalent to the stock shown in the third order description of the stock and flow structure, and as such is not used by the model equations.

## **A.2 Third Order Delay Structure**

### **A.2.1 Capacity 1 (seats)**

$$= \int (\text{NewCapacity} - \text{Cap1to2}) dt + [\text{InitialAirlineCapacity}/3]$$

**New Capacity (seats/Year)**

$$= \text{AirplaneManufacturingCompletion}$$

**Airplane Manufacturing Completion is a variable covered in A.1.1**

**Cap 1 to 2 (seats/Year)**

$$= \text{Capacity1}/(\text{AverageServiceLife}/3)$$

**Capacity 1 is a variable covered in A.2.1**

**Average Service Life is a variable covered in A.1.1**

**Initial Airline Capacity is a variable covered in A.1.1**

### **A.2.2 Capacity 2 (seats)**

$$= \int (\text{Cap1to2} - \text{Cap2to3}) dt + [\text{InitialAirlineCapacity}/3]$$

**Cap 1 to 2 is a variable covered in A.2.1**

**Cap 2 to 3 (seats/Year)**

$$= \text{Capacity2}/(\text{AverageServiceLife}/3)$$

**Capacity 2 is a variable covered in A.2.2**

**Average Service Life is a variable covered in A.1.1**

**Initial Airline Capacity is a variable covered in A.1.1**

### **A.2.3 Capacity 3 (seats)**

$$= \int (\text{Cap2to3} + \text{ReturntoService} - \text{IntoStorage} - \text{Retired}) dt + [\text{InitialAirlineCapacity}/3]$$

**Cap 2 to 3 is a variable covered in A.2.2**

#### **Return to Service (seats/Year)**

$$= \text{IFTHENELSE}(\text{IndicatedCapacityAdjustment} > 0, \\ \text{CapacityonMothball}/\text{TimetoUnMothball}, 0)$$

Description: this is the flow of planes off of mothballing and back into the stock of capacity

**Indicated Capacity Adjustment is a variable covered in A.1.2**

**Capacity on Mothball is a variable covered in A.2.4**

#### **Time to UnMothball (years) 0.5**

Description: The length of time needed to take a mothballed airplane and return it to service

#### **Into Storage (seats/Year)**

$$= \text{IFTHENELSE}(\text{Time} > 1980, \text{IFTHENELSE}(((1 - \text{SwitchforHistoricalVariables}) * \text{OperatingMargin} + (\text{SwitchforHistoricalVariables}) * \text{HistoricalAirlineOperatingMargin}) \\ \leq \text{MarginThresholdtoInitiateMothballing}, \text{IFTHENELSE}(\text{IndicatedCapacityAdjustment} < 0, \text{Min}(-\text{IndicatedCapacityAdjustment}, \text{Capacity3}/\text{TimetoMothball}), 0), 0), 0)$$

Description: This is the flow of planes into mothballing

#### **Switch for Historical Variables (dmnl) 0**

Description: Set this variable to zero in order to use historical inputs for all of the model sectors

**Operating Margin is a variable covered in A.10.2**

**Historical Airline Operating Margin is a variable covered in A.10.4**

#### **Margin Threshold to Initiate Mothballing (fraction) 0**

Description: this is the operating margin threshold that will cause airlines to mothball capacity

**Indicated Capacity Adjustment is a variable covered in A.1.2**

**Capacity 3 is a variable covered in A.2.3**

**Time to Mothball (years) 0.25**

Description: this is how long it takes airlines to mothball capacity

**Retired (seats/Year)**

$$= \text{Capacity3}/(\text{AverageServiceLife}/3)$$

**Capacity 3 is a variable covered in A.2.3**

**Average Service Life is a variable covered in A.1.1**

**Initial Airline Capacity is a variable covered in A.1.1**

**A.2.4 Capacity on Mothball (seats)**

$$= \int (\text{IntoStorage} - \text{ReturntoService}) dt + [0]$$

Description: This is the stock of planes waiting on mothball

**Into Storage is a variable covered in A.2.3**

**Return to Service is a variable covered in A.2.3**

**A.2.5 Capacity on Order 1 (Seat)**

$$= \int (\text{Ordering} - 1\text{to}2 - \text{CancelledOrders}) dt + [\text{InitialCapacityonOrder}/3]$$

Description: this is the first stock of airline capacity on order

**Ordering (Seat/Year)**

$$= \text{OrdersofAirplanes}$$

Description: this lower structure represents the fact that airplane ordering is a higher order delay process than would be indicated by the one stock representation above

**Orders of Airplanes is a variable covered in A.1.2**

**1 to 2 (Seat/Year)**

$$= \text{CapacityonOrder1}/(\text{TimeRequiredtoManufactureanAirplane}/3)$$

Description: This is the flow of material from the first third of the delay to the second

**Capacity on Order 1 is a variable covered in A.2.5**

**Time Required to Manufacture an Airplane is a variable covered in A.1.1**

**Cancelled Orders is a variable covered in A.1.2**

**Initial Capacity on Order is a variable covered in A.1.2**

### **A.2.6 Capacity on Order 2 (Seat)**

$$= \int (1 \text{ to } 2 - 2 \text{ to } 3) dt + [\text{Initial Capacity on Order} / 3]$$

Description: This is the stock of Capacity on Order in the second stage of production

**1 to 2 is a variable covered in A.2.5**

**2 to 3 (Seat/Year)**

$$= \text{Capacity on Order } 2 / (\text{Time Required to Manufacture an Airplane} / 3)$$

Description: This is the flow of airplanes from the second stock to the third

**Capacity on Order 2 is a variable covered in A.2.6**

**Time Required to Manufacture an Airplane is a variable covered in A.1.1**

**Initial Capacity on Order is a variable covered in A.1.2**

### **A.2.7 Capacity on Order 3 (Seat)**

$$= \int (2 \text{ to } 3 - \text{Completion}) dt + [\text{Initial Capacity on Order} / 3]$$

Description: This is the stock of airplanes ordered that is nearing delivery

**2 to 3 is a variable covered in A.2.6**

**Completion is a variable covered in A.1.1**

**Initial Capacity on Order is a variable covered in A.1.2**

## **A.3 Forecasting**

### **A.3.1 Expected Growth Rate for Demand (dmnl/Year)**

$$= \int (\text{Change in Expected Growth Rate}) dt + [\text{Initial Expected Growth Rate in Demand}]$$

**Change in Expected Growth Rate (dmnl/Year/Year)**

$$= (\text{Indicated Growth Rate} - \text{Expected Growth Rate for Demand}) / \text{Time to Perceive Trend in Demand} * (1 - \text{Switch for Partial Model Tests})$$

**Indicated Growth Rate (dmnl/Year)**  

$$= (\text{PerceivedDemand} - \text{ReferenceDemand}) / (\text{ReferenceDemand} * \text{TimeHorizonforReferenceDemand})$$

**Perceived Demand is a variable covered in A.3.2**

**Reference Demand is a variable covered in A.3.3**

**Time Horizon for Reference Demand is a variable covered in A.3.3**

**Expected Growth Rate for Demand is a variable covered in A.3.1**

**Time to Perceive Trend in Demand (Year) 0.3**

**Switch for Partial Model Tests is a variable covered in A.1.1**

**Initial Expected Growth Rate in Demand (dmnl/Year)**

$$= \text{FirstExpectedGrowthRate} * (1 - \text{SwitchforPartialModelTests}) + \text{PartialModelGrowthRate} * \text{SwitchforPartialModelTests}$$

**First Expected Growth Rate (dmnl/Year) 0**

Description:

**Switch for Partial Model Tests is a variable covered in A.1.1**

**Partial Model Growth Rate (dmnl/Year) 0.05**

Description:

**A.3.2 Perceived Demand (Seat\*miles/Year)**

$$= \int (\text{ChangeinDemandPerception}) dt + [\text{ActualDemandForSeatMiles}]$$

Description: This is the industry's perception of the total demand for seat miles

**Change in Demand Perception (Seat\*miles/Year/Year)**

$$= \text{GapinDemandPerception} / \text{TimetoPerceiveChangesinDemand}$$

**Gap in Demand Perception (Seat\*miles/Year)**

$$= (\text{HistoricalAirlineDemand} * \text{SwitchforHistoricalVariables} + (1 - \text{SwitchforHistoricalVariables}) * \text{ActualDemandForSeatMiles}) - \text{PerceivedDemand}$$

**Historical Airline Demand is a variable covered in A.5.2**

**Switch for Historical Variables is a variable covered in B.1.2**

**Actual Demand For Seat Miles is a variable covered in A.5.1**

**Perceived Demand is a variable covered in A.3.2**

**Time to Perceive Changes in Demand (Year) 0.125**

Description: This is how long it takes the industry to perceive changes in demand and for their calculation of desired capacity

**Actual Demand For Seat Miles is a variable covered in A.5.1**

**A.3.3 Reference Demand (Seat\*miles/Year)**

$$= \int (\text{Change in Reference Demand}) dt + [\text{Perceived Demand} / (1 + \text{Initial Expected Growth Rate in Demand} * \text{Time Horizon for Reference Demand})]$$

**Change in Reference Demand (Seat\*miles/Year/Year)**

$$= (\text{Perceived Demand} - \text{Reference Demand}) / \text{Time Horizon for Reference Demand}$$

**Perceived Demand is a variable covered in A.3.2**

**Reference Demand is a variable covered in A.3.3**

**Time Horizon for Reference Demand (Year) 5**

Description:

**Perceived Demand is a variable covered in A.3.2**

**Initial Expected Growth Rate in Demand is a variable covered in B.6.1**

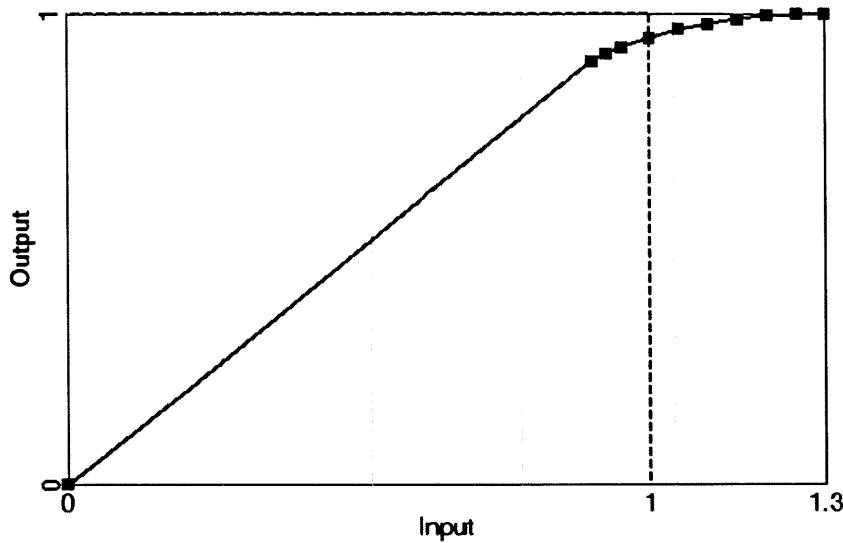
**Time Horizon for Reference Demand is a variable covered in A.3.3**

**A.4 Available Seat Miles**

**A.4.1 Load Factor (fraction)**

$$= \text{Table for the Load Factor Experienced}(\text{Indicated Load Factor})$$

Description: Load factor is defined as the revenue passenger miles divided by the available seat miles, however since the model aggregates over all of the routes in the industry, we calculate load factor as the output of that ratio in a table function



**Figure A-1: Table for the Load Factor Experienced**

**Table for the Load Factor Experienced (dmnl)**

= [(0,0)-(1.3,1)],(0,0),(0.9,0.9),(0.925,0.9175),(0.95,0.93),(1,0.95),(1.05,0.9675),  
 (1.1,0.98),(1.15,0.99),(1.2,0.9975),(1.25,1),(1.3,1)

Description:

**Indicated Load Factor (dmnl)**

= ActualDemandForSeatMiles/AvailableSeatMiles

Description: The indicated load factor is the load factor that the industry would experience if there were only one route and one time slot that everyone wanted to fly. Multiple routes cause some to be oversubscribed relative to others and the overall load factor to be different.

**Actual Demand For Seat Miles is a variable covered in A.5.1**

**Available Seat Miles (Seat\*miles/Year)**

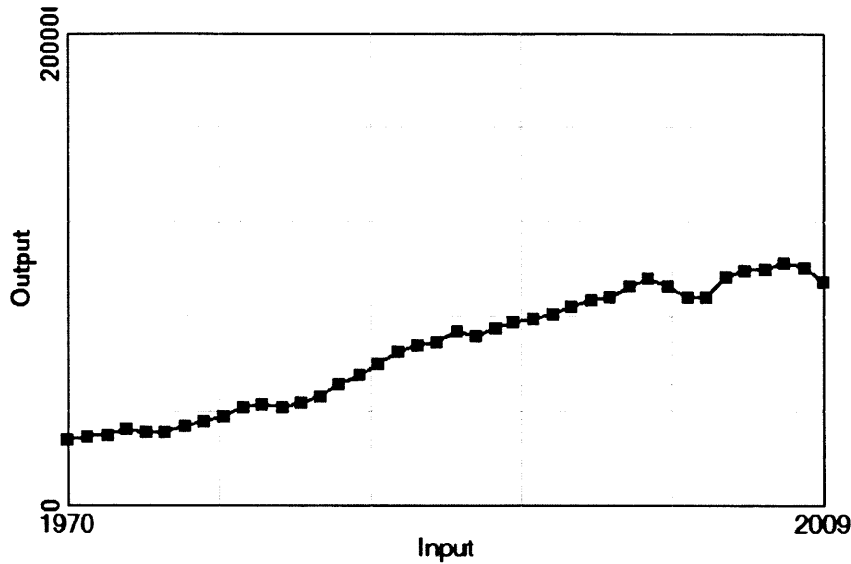
= AirlineCapacity\*NumberofMilesFlownperSeat

Description: The number of seat miles the airlines fly in a given year is the number of seats of capacity they operate multiplied by the number of miles flown by each seat

**Airline Capacity is a variable covered in A.1.1**

**Number of Miles Flown per Seat (miles/Year)**

= DaysperYear\*Milestraveledperhourflown\*NormalNumberofHoursFlownperDay



**Figure A-2: Table for Historical Airline Available Seat Miles**

Description: This is the number of miles the airlines would like to use each seat every year

- Days per Year (days/Year)

365

Description: The number of days in a year

- Miles traveled per hour flown (miles/hour)

160

Description: This is the average number of miles flown per hour

- Normal Number of Hours Flown per Day (hours/day)

9

Description: This is the normal number of flying hours each plane gets per day, found from the constant part of the regression of plane utilization on load factor

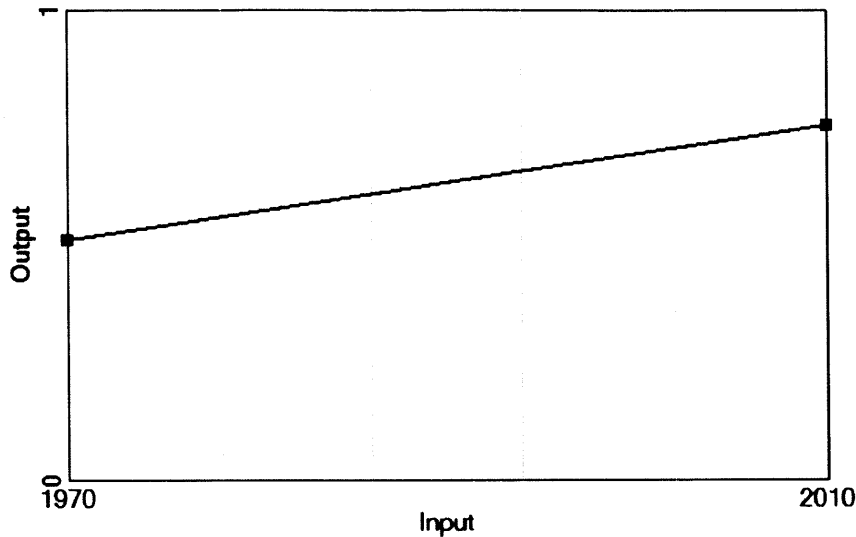
#### A.4.2 Historical Available Seat Miles (Seat\*miles/Year)

= TableforHistoricalAirlineAvailableSeatMiles(Time-1)\*1e+006

#### Table for Historical Airline Available Seat Miles (Seat\*miles/Year)

=[(1970,0)-(2009,2e+006)],(1970,280000),(1971,294344),(1972,300245),  
(1973,325160),(1974,309422),(1975,314873),(1976,337529),(1977,360141),  
(1978,379781),(1979,418114),(1980,431980),(1981,420058),(1982,434670)





**Figure A-3: Table Function for Normal Load Factor**

,(1983,466069),(1984,515628),(1985,552619),(1986,604505),(1987,653612)  
 ,(1988,682250),(1989,694087),(1990,740851),(1991,717562),(1992,755986)  
 ,(1993,777360),(1994,792632),(1995,815571),(1996,844037),(1997,871964)  
 ,(1998,882173),(1999,927892),(2000,962464),(2001,931858),(2002,883071)  
 ,(2003,886798),(2004,968696),(2005,999688),(2006,1.00119e+006)  
 ,(2007,1.03161e+006),(2008,1.01234e+006),(2009,950656)

Description: The available seat miles of the airline industry, as given by the air transport association

### A.4.3 Normal Load Factor (fraction)

= TableFunctionforNormalLoadFactor(Time)

Description: This is the desired load factor of the industry as a whole, it increases with time due to improvements in technology, load management and mechanisation.

#### Table Function for Normal Load Factor (dmnl)

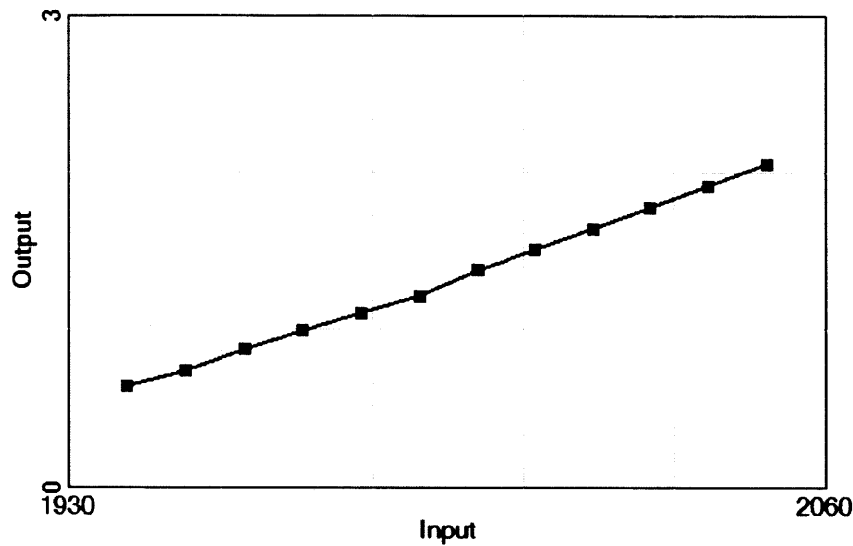
= [(1970,0)-(2010,1)],(1970,0.5114),(2010,0.7554)

Description: I estimate the best fit line around historically observed load factors as the current normal load factor in the model

## A.5 Demand

### A.5.1 Actual Demand For Seat Miles (Seat\*miles/Year)

= Population\*DemandforSeatMilesperCapita



**Figure A-4: Historical Population Data and Projections**

Description: This is the real demand for seat miles seen by the airlines

**Population (people)**

= InitialPopulation\*HistoricalPopulationDataandProjections(Time-1)

Description: This is the population of the United States

**Initial Population (people) 203302000**

Description: This is the population of the US at the beginning of the model run

**Historical Population Data and Projections (dmnl)** =[(1930,0)-(2060,3)]  
 ,(1940,0.65),(1950,0.74434),(1960,0.88205),(1970,1),(1980,1.1143)  
 ,(1990,1.223),(2000,1.3842),(2010,1.5157),(2020,1.6476)  
 ,(2030,1.7843),(2040,1.9235),(2050,2.06)

Description: This is the historical data on US population normalized to the population at the beginning of the model run. Includes government projections of future population for the life of the model run

**Demand for Seat Miles per Capita is a variable covered in A.5.2**

**A.5.2 Demand for Seat Miles per Capita  
 (Seat\*mile/Year/people)**

=EffectofCongestiononDemand\*EffectofAffordabilityonDemand  
 \*EffectofNewCapacityonDemand\*

TotalSeatMilesDesiredfromGDPperCapita\*9/11EffectOnDemand

Description: This is the yearly demand for seat miles per person

### Effect of Congestion on Demand (dmnl)

= smoothi(IndicatedEffectofCongestiononDemand,CongestionPerceptionTime,1)

Description: It will take a certain amount of time for passengers to change their attitudes about how congested flights will be.

### Indicated Effect of Congestion on Demand (dmnl)

= (Congestion)<sup>^</sup>SensitivityofDemandtoCongestion

Description: When load factor is very high people will be dissatisfied with their flying experience and choose alternative modes of transportation if possible.

**Congestion (dmnl)** = (SwitchforHistoricalVariables\*  
HistoricalAirlineLoadFactor+IndicatedLoadFactor\*  
(1-SwitchforHistoricalVariables))/NormalLoadFactor

Description: The measure of congestion is the current load factor divided by the normal load factor the airlines can handle

- Switch for Historical Variables is a variable covered in B.1.2
- Historical Airline Load Factor (fraction)

= HistoricalAirlineDemand/HistoricalAvailableSeatMiles

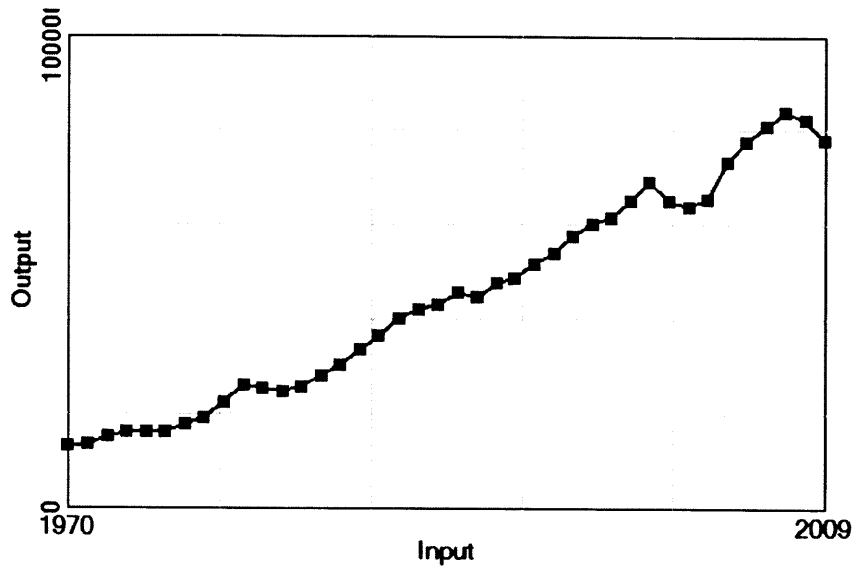
Description: The load factors experienced by the industry

– Historical Airline Demand (Seat\*miles/Year)  
= TableforHistoricalAirlineDemad(Time-1)\*1e+006

\* Table for Historical Airline Demad (Seat\*miles/Year)  
=[(1970,0)-(2009,1e+006)],(1970,131710),(1971,135658)  
,(1972,152406),(1973,161957),(1974,162919),(1975,162810)  
,(1976,178988),(1977,193219),(1978,226781),(1979,262023)  
,(1980,255192),(1981,248888),(1982,259644),(1983,281829)  
,(1984,305116),(1985,336403),(1986,366546),(1987,404471)  
,(1988,423302),(1989,432714),(1990,457926),(1991,447955)  
,(1992,478554),(1993,489684),(1994,519382),(1995,540656)  
,(1996,578663),(1997,603419),(1998,618087),(1999,652047)  
,(2000,692757),(2001,651700),(2002,641102),(2003,656909)  
,(2004,733680),(2005,779004),(2006,809755),(2007,840759)  
,(2008,822435),(2009,779511)

– Historical Available Seat Miles is a variable covered in A.4.2

- Indicated Load Factor is a variable covered in A.4.1
- Normal Load Factor is a variable covered in A.4.3



**Figure A-5: Table for Historical Airline Demand**

**Sensitivity of Demand to Congestion (dmnl) -0.726**

Description: Demand is lower when people feel that flights are too congested, this will manifest as a negative sensitivity of demand to congestion.

**Congestion Perception Time (Year) 0.75**

Description: The perception of the airline industry's congestion takes a while to change

**Effect of Affordability on Demand (dmnl)**

$$= \frac{\text{ReferenceTicketPrice}}{((\text{SwitchforHistoricalVariables}) * \text{HistoricalAirlineTicketPrices} + (1 - \text{SwitchforHistoricalVariables}) * \text{TicketPrice})} \wedge \text{StrengthofAffordabilityEffectonDemand}$$

Description: This measures the change in demand due to changes in ticket price charged by the airlines

**Reference Ticket Price (dollars/(Seat\*mile)) = InitialTicketPrice\*CPI**

Description: This is the GDP per capita adjusted ticket price relative to the initial price

**Initial Ticket Price is a variable covered in A.6.1**

**CPI (dmnl) =  $\int (\text{CPI} * \text{CPIPercentageChange}) dt + [1]$**

Description: With 1977 as a value of 1

- CPI Percentage Change is a variable covered in A.8.1

**Switch for Historical Variables is a variable covered in B.1.2**

**Historical Airline Ticket Prices is a variable covered in A.6.2**

**Ticket Price is a variable covered in A.6.1**

**Strength of Affordability Effect on Demand (dmnl) 0.106**

Description: This controls how steep or shallow the response of demand is to changes in the price of airfare compared to a basket of representative goods

**Effect of New Capacity on Demand (dmnl)**

$= 1 + \text{Max}(\text{OneYearPercentChangeinCapacity} * \text{StrengthofNewCapacityEffectonDemand}, 0)$

Description: New Capacity will effect how many seat miles the average person demands because new capacity represents new routes and schedules that will spur demand

**One Year Percent Change in Capacity (dmnl)**

$= \text{AvailableSeatMiles} / \text{SMOOTH}(\text{AvailableSeatMiles}, \text{LagforMeasuringChanges}) - 1$

Description: The recent change in seat miles made available by the airlines

**Available Seat Miles is a variable covered in A.4.1**

**Lag for Measuring Changes (Year) 1**

Description:

**Strength of New Capacity Effect on Demand (dmnl) 0.25**

Description: The number of seat miles demanded per capita for every increase of one seat mile offered by the airlines

**Total Seat Miles Desired from GDP per Capita (Seat\*mile/Year/people)**

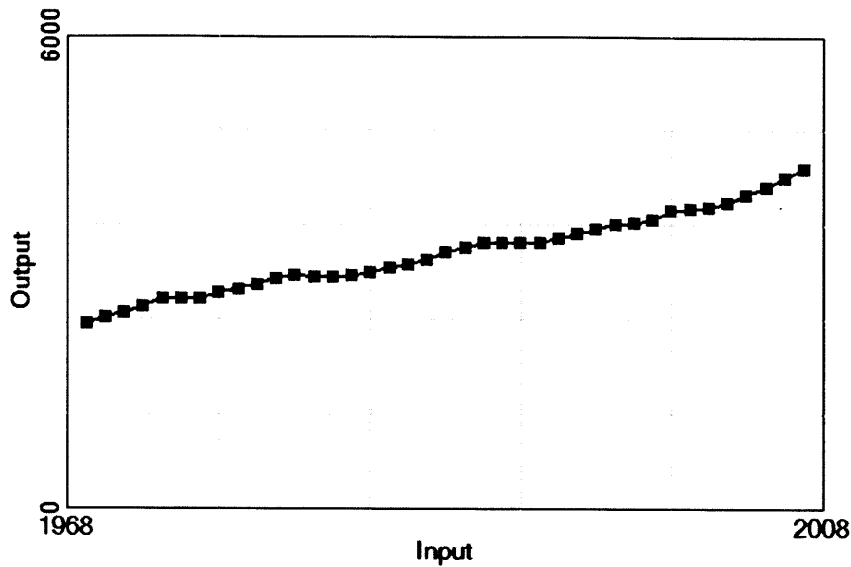
$= \text{WorldSeatMilesDesiredfromGDPperCapita} + \text{SeatMilesDesiredfromGDPperCapita}$

Description:

**World Seat Miles Desired from GDP per Capita (Seat\*miles/person/Year)**

$= \text{WorldGDPperCapita} * \text{WorldMilesperPersonperDollarofGDP}$

Description: This variable adjusts demand based on the affect of changes in consumer income compared to a reference level



**Figure A-6: World Historical GDP Data**

**World GDP per Capita (dollars/person)**

= WorldHistoricalGDPData(Time-1)

Description: this is the GDP per capita in america

- World Historical GDP Data (dollars/person)

=[(1968,0)-(2008,6000)],(1969,2351),(1970,2444),(1971,2492),(1972,2574)  
 ,(1973,2683),(1974,2682),(1975,2674),(1976,2749),(1977,2801)  
 ,(1978,2861),(1979,2939),(1980,2964),(1981,2959),(1982,2948)  
 ,(1983,2962),(1984,3015),(1985,3061),(1986,3108),(1987,3170)  
 ,(1988,3262),(1989,3327),(1990,3375),(1991,3393),(1992,3394)  
 ,(1993,3391),(1994,3441),(1995,3496),(1996,3558),(1997,3628)  
 ,(1998,3634),(1999,3679),(2000,3789),(2001,3811),(2002,3838)  
 ,(2003,3891),(2004,4002),(2005,4094),(2006,4215),(2007,4334)

Description: This is the historical world GDP per capita expressed in real 2000 dollars

**World Miles per Person per Dollar of GDP ((Seat\*miles)/(Year\*\$))**

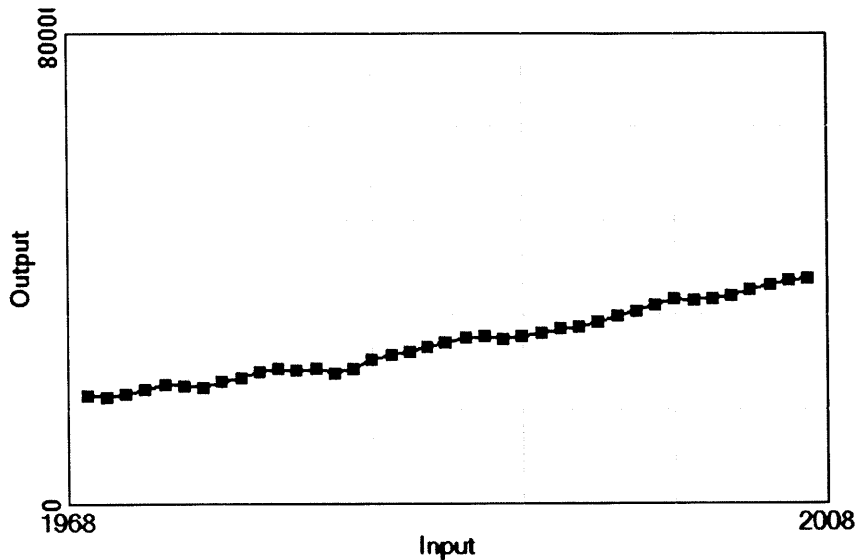
0.05

Description: The number of miles demanded per dollar of GDP per capita

**Seat Miles Desired from GDP per Capita (Seat\*miles/person/Year)**

= GDPperCapita\*MilesperPersonperDollarofGDP+ConstantDemandAdjustment

Description: This variable adjusts demand based on the affect of changes in consumer income compared to a reference level



**Figure A-7: Historical GDP Data**

**GDP per Capita (dollars/person) = Historical GDP Data(Time-1)**

Description: this is the GDP per capita in america

- Historical GDP Data (dollars/person)

=[(1968,0)-(2008,80000)],(1969,18578),(1970,18395),(1971,18774),(1972,19557),  
 ,(1973,20488),(1974,20199),(1975,19962),(1976,20826),(1977,21570),(1978,22531)  
 ,(1979,22987),(1980,22666),(1981,23011),(1982,22350),(1983,23148),(1984,24598)  
 ,(1985,25386),(1986,26028),(1987,26668),(1988,27519),(1989,28226),(1990,28435)  
 ,(1991,28011),(1992,28559),(1993,28943),(1994,29744),(1995,30131),(1996,30886)  
 ,(1997,31891),(1998,32837),(1999,33908),(2000,34770),(2001,34701),(2002,34931)  
 ,(2003,35479),(2004,36433),(2005,37206),(2006,37928),(2007,38340)

Description: This is the historical GDP per capita expressed in real 2000 dollars

**Miles per Person per Dollar of GDP ((Seat\*miles)/(Year\*\$))**

0.093

Description: The number of miles demanded per dollar of GDP per capita

**Constant Demand Adjustment (Seat\*miles/person/Year)**

-1087.68

9/11 Effect On Demand is a variable that is covered in A.11.1

## A.6 Price Setting

### A.6.1 Ticket Price (dollars/(Seat\*mile))

$$= \int (\text{Change in Ticket Price}) dt + [\text{Initial Ticket Price}]$$

Description: This is the expected ticket price of the airlines

### Change in Ticket Price (dollars/(Seat\*mile)/Year)

$$= (\text{Indicated Ticket Price per Seat Mile} - \text{Ticket Price}) / \text{Time to Adjust Ticket Prices}$$

Description: This is the process of adjustment in the airlines expected ticket price

### Indicated Ticket Price per Seat Mile (dollars/(Seat\*mile))

$$= \text{Ticket Price} * \text{Effect of Demand Supply Balance on Price}$$

$$+ \text{Effect of Margin on Price} * \text{Effect of Cost on Price}$$

Description: This is the ticket price per seat mile

**Ticket Price is a variable covered in A.6.1**

### Effect of Demand Supply Balance on Price (dmnl)

$$= \text{Current Demand Supply Balance} \wedge \text{Sensitivity of Price to Demand Supply Balance}$$

Description: When load factors are high the industry can raise prices because demand is robust compared to the supply of seats. When load factors are below the target prices feel a downward pressure because there is little demand relative to the number of seats being offered in the industry

- Current Demand Supply Balance (dmnl)

$$= (\text{Historical Airline Load Factor} * \text{Switch for Historical Variables} + (1 - \text{Switch for Historical Variables}) * \text{Load Factor}) / \text{Normal Load Factor}$$

Description: Computes the ratio of total airline demand to "normal" demand

- Historical Airline Load Factor is a variable covered in A.5.2
- Switch for Historical Variables is a variable covered in B.1.2
- Load Factor is a variable covered in A.4.1
- Normal Load Factor is a variable covered in A.4.3

- Sensitivity of Price to Demand Supply Balance (dmnl)

$$= \text{Original Sensitivity of Price to Demand Supply Balance} + \text{Effect of Yield Management on Sensitivity} *$$

$$\text{IF THEN ELSE}(\text{Time} > \text{Yield Management Introduction Year}, 1, 0)$$

Description: Once yield management is introduced the sensitivity of price to the demand supply balance is instantly increased by the indicated level.



- Original Sensitivity of Price to Demand Supply Balance (dmnl [0,3])  
0.25  
Description: The sensitivity of airline prices to load factors before the introduction of yield management
- Effect of Yield Management on Sensitivity (dmnl [0,3])  
2.25  
Description: Yield Management increases the sensitivity of prices to load factors because load factors are the main component determining the price of seats
- Yield Management Introduction Year (Year)  
1987  
Description: American Airlines introduction of ultimate super saver fares occurred on January 17th 1985, I add one year for thereporting process and one year for widespread adoption

#### **Effect of Margin on Price (dmnl)**

$$= (\text{PressurefromMargin})^{\wedge} \text{SensitivityofPricetoMargin}$$

Description:

- Pressure from Margin (dmnl)

$$= (1 + \text{TargetMargin}) / (1 + \text{HistoricalAirlineOperatingMargin} * \text{SwitchforHistoricalVariables} + (1 - \text{SwitchforHistoricalVariables}) * \text{OperatingMargin})$$

Description: The ratio of actual (historical) margin and the target margin

- Target Margin (dmnl [0,0.1])  
0.05  
Description: The level of operating margin where pressures on ticket price change from being positive to being negative
- Historical Airline Operating Margin is a variable covered in A.10.4
- Switch for Historical Variables is a variable covered in B.1.2
- Operating Margin is a variable covered in A.10.2

- Sensitivity of Price to Margin (dmnl)

0.4

Description:

#### **Effect of Costs on Price (dmnl)**

$$= \text{PressurefromCosts}^{\wedge} \text{SensitivityofPricetoCosts}$$

Description:

- Pressure from Costs (dmnl)

$$= (\text{Current Operating Costs per Seat Mile} - \text{Expected Ancillary Fee Revenue per Revenue Passenger Mile}) \cdot (1 + \text{Target Percentage Above Cost}) / \text{Ticket Price}$$

Description: The current level of pressure from costs on ticket price, before the sensitivity is taken into account

- Current Operating Costs per Seat Mile (dollars/(Seat\*mile))

$$= ((\text{Switch for Historical Variables}) \cdot \text{Historical Operating Cost per Available Seat Mile} + (1 - \text{Switch for Historical Variables}) \cdot \text{Cost per Available Seat Mile})$$

Description: The operating costs of the airline industry per available seat mile. This equation allows for switching between historical and simulated time series'.

- \* Switch for Historical Variables is a variable covered in B.1.2

- \* Historical Operating Cost per Available Seat Mile  
Historical Airline Passenger Operating Costs is a variable covered in A.10.4

- \* Historical Available Seat Miles is a variable covered in A.4.2

- \* Cost per Available Seat Mile is a variable covered in A.7.1

- Expected Ancillary Fee Revenue per Revenue Passenger Mile (dollars/(Seat\*mile))

$$= \text{Historical Ancillary Fee Revenue} / \text{Historical Available Seat Miles}$$

Description: The expected ancillary fee revenue per seat mile sold

- \* Historical Ancillary Fee Revenue (dollars/Year)

$$= \text{Table for Ancillary Fees}(\text{Time}-1) \cdot 1000$$

Description: Fees in the table are recorded in thousands of dollars per year

- Table for Ancillary Fees (dollars/Year)

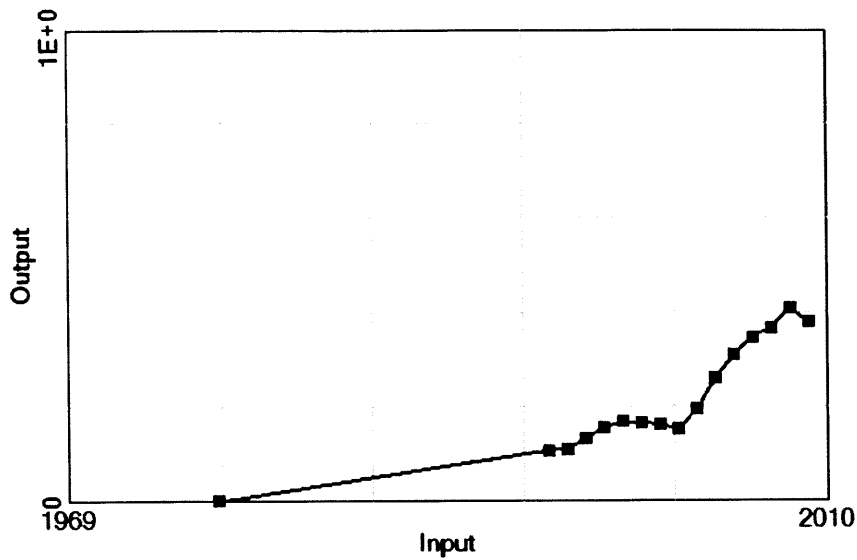
$$= [(1969, 0) - (2010, 1e+008)], (1977, 0), (1995, 1.07815e+007), (1996, 1.11052e+007), (1997, 1.33417e+007), (1998, 1.57061e+007), (1999, 1.67841e+007), (2000, 1.67335e+007), (2001, 1.62059e+007), (2002, 1.52043e+007), (2003, 1.95053e+007), (2004, 2.60094e+007), (2005, 3.10487e+007), (2006, 3.48475e+007), (2007, 3.67713e+007), (2008, 4.08706e+007), (2009, 3.78906e+007)$$

Description: Ancillary fees have only recently been added to the income stream of airlines, they are an important cause of the relatively low yield per revenue passenger mile in the past decade

- \* Historical Available Seat Miles is a variable covered in A.4.2

- Target Percentage Above Cost (dmnl)

0.54



**Figure A-8: Table for Ancillary Fees**

Description: this is the level of profitability where airlines will no longer raise fares

– Ticket Price is a variable covered in A.6.1

- Sensitivity of Price to Costs (dmnl)

0.3

Description:

**Ticket Price is a variable covered in A.6.1**

**Time to Adjust Ticket Prices (Year) 0.05**

Description: This is how long it takes airlines to adjust prices to the level suggested by the indicated price

**Initial Ticket Price (dollars/(Seat\*mile))**

0.0797

Description: The initial ticket price

**A.6.2 Historical Airline Ticket Prices (dollars/(Seat\*mile))**

= TableforHistoricalAirlineTicketPrices(Time-1)

Description: The actual ticket prices charged by the industry in nominal dollars (cents)

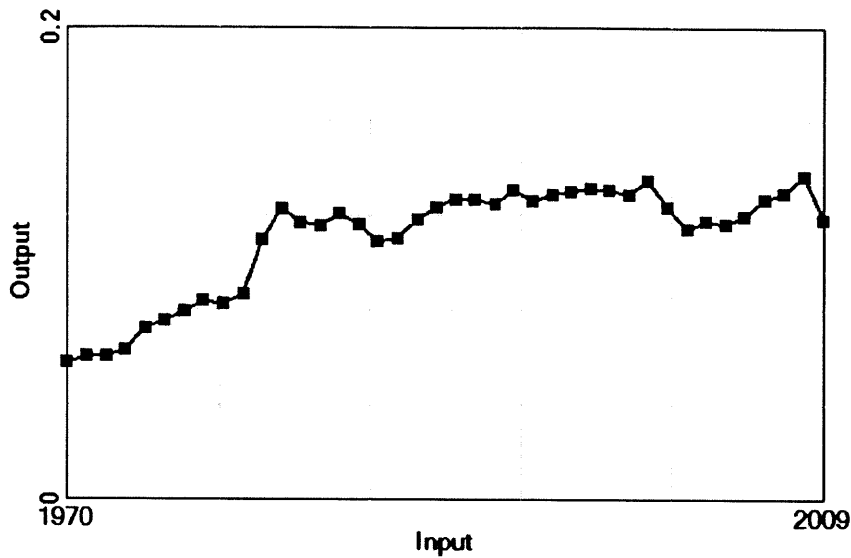


Figure A-9: Table for Historical Airline Ticket Prices

### Table for Historical Airline Ticket Prices (dollars/(Seat\*mile))

=[(1970,0)-(2009,0.2)],(1970,0.0579),(1971,0.0606),(1972,0.0608),(1973,0.0634)  
 ,(1974,0.0729),(1975,0.0759),(1976,0.0797),(1977,0.0842),(1978,0.0829),(1979,0.087)  
 ,(1980,0.1099),(1981,0.1234),(1982,0.1177),(1983,0.1162),(1984,0.1211),(1985,0.1166)  
 ,(1986,0.1093),(1987,0.1111),(1988,0.1188),(1989,0.1243),(1990,0.1276),(1991,0.1274)  
 ,(1992,0.1251),(1993,0.1313),(1994,0.1265),(1995,0.1292),(1996,0.1305),(1997,0.1318)  
 ,(1998,0.1311),(1999,0.1294),(2000,0.1351),(2001,0.1242),(2002,0.1145),(2003,0.1178)  
 ,(2004,0.1167),(2005,0.12),(2006,0.1273),(2007,0.1298),(2008,0.1373),(2009,0.1187)

Description:

## A.7 Operating Costs

### A.7.1 Cost per Available Seat Mile (dollars/(Seat\*mile))

=OperatingCostsfromPassengers/(HistoricalAvailableSeatMiles  
 \*SwitchforHistoricalVariables+(1-SwitchforHistoricalVariables)  
 \*AvailableSeatMiles)

Description: this is the current cost the airlines see per seat mile they fly. It will serve as the at cost ticket price for the airlines

**Operating Costs from Passengers is a variable covered in A.7.2**

**Historical Available Seat Miles is a variable covered in A.4.2**

**Switch for Historical Variables is a variable covered in B.1.2**

**Available Seat Miles is a variable covered in A.4.1**

### **A.7.2 Total Operating Costs (dollars/Year)**

= OperatingCostsfromPassengers

Description:

### **Operating Costs from Passengers (dollars/Year)**

= VariableCostfromOperations+CostsfromWages

Description: This is the sum of all costs of the airlines

### **Variable Cost from Operations (dollars/Year)**

=(HistoricalAvailableSeatMiles\*SwitchforHistoricalVariables

+(1-SwitchforHistoricalVariables)\*AvailableSeatMiles)

\*VariableCostsperSeatMile

Description: This is the variable cost of operations the airlines see

**Historical Available Seat Miles is a variable covered in A.4.2**

**Switch for Historical Variables is a variable covered in B.1.2**

**Available Seat Miles is a variable covered in A.4.1**

### **Variable Costs per Seat Mile (dollars/(Seat\*mile))**

= VariableCostsfromJetFuel+OtherVariableCosts

Description: This is the variable cost of running a seat for an hour

• Variable Costs from Jet Fuel (\$/(Seat\*mile))

= FuelCostperGallon\*GallonsperSeatMile

Description: This is the variable cost seen per dollar of jet fuel costs

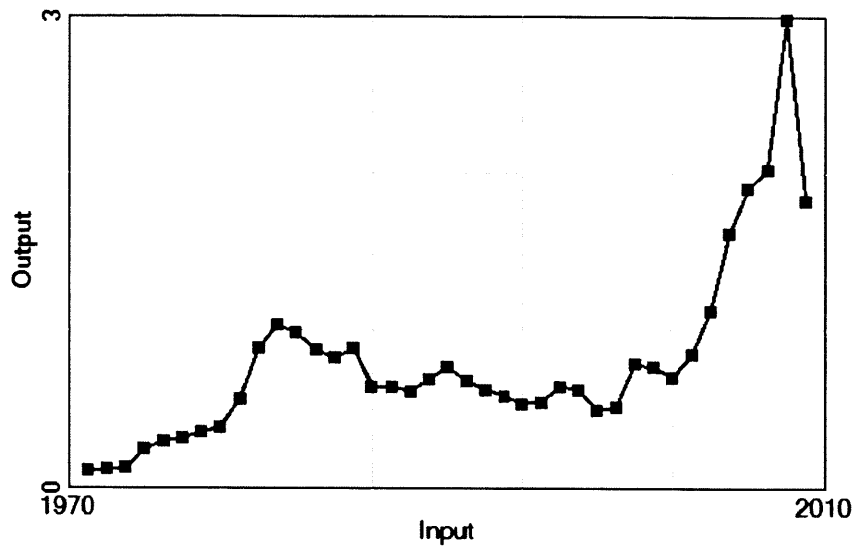
– Fuel Cost per Gallon (\$/gallon)

= HistoricalJetFuelCost(Time-1)

Description: This is the fuel cost per gallon backsolved from ATA cost tables to remove the effects of hedging

\* Historical Jet Fuel Cost (dollars/gallon)

=[(1970,0)-(2010,3)],(1971,0.11),(1972,0.12),(1973,0.13),(1974,0.25)  
,(1975,0.3),(1976,0.32),(1977,0.36),(1978,0.39),(1979,0.57),(1980,0.89)  
,(1981,1.04),(1982,0.99),(1983,0.88),(1984,0.83),(1985,0.89)



**Figure A-10: Historical Jet Fuel Cost**

,(1986,0.65),(1987,0.65),(1988,0.62),(1989,0.7),(1990,0.77)  
 ,(1991,0.69),(1992,0.63),(1993,0.59),(1994,0.54),(1995,0.55)  
 ,(1996,0.65),(1997,0.63),(1998,0.5),(1999,0.52),(2000,0.79)  
 ,(2001,0.77),(2002,0.71),(2003,0.85),(2004,1.13),(2005,1.62)  
 ,(2006,1.91),(2007,2.03),(2008,2.98),(2009,1.83)

Description: The historical cost of jet fuel is taken from a calculation performed by the ATA in the cost index tables available for download from their website

– Gallons per Seat Mile (gallons/(Seat\*mile) [0,0.06])

= TableforHistoricalGallonsperSeatMile(Time-1)

Description: This is the number of gallons of jet fuel used ber seat mile

\* Table for Historical Gallons per Seat Mile (gallons/(Seat\*mile))

=[(1970,0.01)-(2010,0.03)],(1970,0.03),(1977,0.0286788)  
 ,(1978,0.0276285),(1979,0.0256997),(1980,0.0237357)  
 ,(1981,0.0249184),(1982,0.0236304),(1983,0.0229709)  
 ,(1984,0.0231163),(1985,0.023007),(1986,0.0225247)  
 ,(1987,0.0223215),(1988,0.0224301),(1989,0.0225935)  
 ,(1990,0.0220211),(1991,0.0213198),(1992,0.0208258)  
 ,(1993,0.020828),(1994,0.0214526),(1995,0.021464)  
 ,(1996,0.0213699),(1997,0.0217202),(1998,0.020843)  
 ,(1999,0.0215229),(2000,0.0198821),(2001,0.0194169)  
 ,(2002,0.0188882),(2003,0.0188717),(2004,0.0186776)  
 ,(2005,0.018264),(2006,0.01776),(2007,0.0174199)  
 ,(2008,0.0173081),(2009,0.0166634)

Description: Historical data from the BTS on the number fo gallons

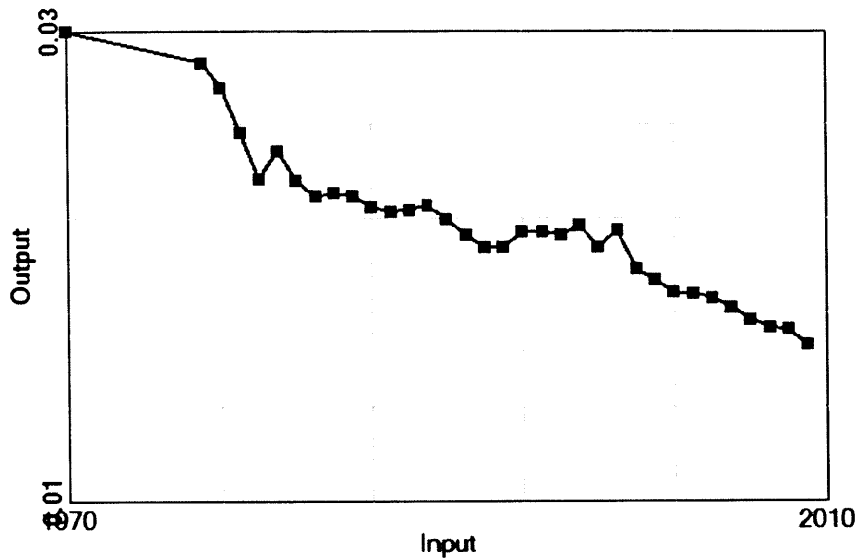


Figure A-11: Table for Historical Gallons per Seat Mile

of fuel used systemwide per available seat mile

- Other Variable Costs (dollars/(Seat\*mile))

$$= \text{ProducerPriceIndex} * 1977\text{OtherVariableCosts}$$

Description: These are all the variable costs other than jet fuel that the airline experiences. Does not include costs from labor expenses or transport related costs. These costs scale with PPI ex food and energy in order to keep them current. There is also an effect on costs from congestion.

- Producer Price Index (dmnl)

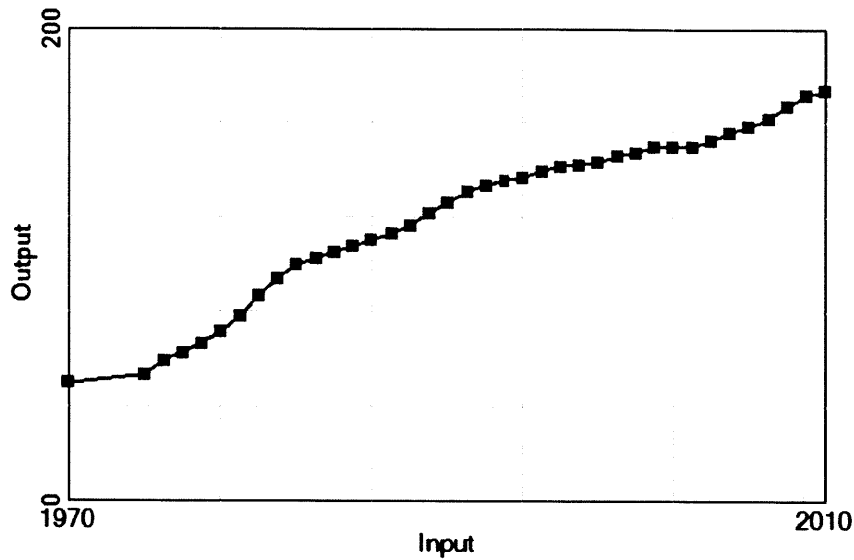
$$= \text{TableforPPIexenergy}(\text{Time}-1)/66.88$$

Description: An Index that measures the average cost of goods for producers in the economy. With 1977 set equal to 1

- \* Table for PPI ex energy (dmnl)

$$= [(1970,0)-(2010,200)], (1970,50), (1974,53.608), (1975,59.742), (1976,63.117), (1977,66.883), (1978,71.9), (1979,78.342), (1980,87.083), (1981,94.6), (1982,99.983), (1983,102.992), (1984,105.558), (1985,108.108), (1986,110.608), (1987,113.292), (1988,116.992), (1989,122.1), (1990,126.583), (1991,131.05), (1992,134.175), (1993,135.792), (1994,137.108), (1995,139.942), (1996,141.992), (1997,142.442), (1998,143.717), (1999,146.083), (2000,147.958), (2001,150.033), (2002,150.133), (2003,150.4), (2004,152.7), (2005,156.342), (2006,158.708), (2007,161.867), (2008,167.417), (2009,171.7), (2010,173.767)$$

- 1977 Other Variable Costs (dollars/(Seat\*mile))



**Figure A-12:** Table for PPI ex energy

0.0245

#### **Costs from Wages (dollars/Year)**

= TotalWorkerSalary

Description: This is the quaterly cost of wages for the airlines

#### **Total Worker Salary (\$/Year)**

= (AverageWorkerCompensation\*(1-SwitchforHistoricalVariables)  
 +HistoricalAirlineSalaries\*SwitchforHistoricalVariables)  
 \*TotalWorkforce

- Average Worker Compensation is a variable covered in A.8.1
- Switch for Historical Variables is a variable covered in B.1.2
- Historical Airline Salaries is a variable covered in A.8.2
- Total Workforce is a variable covered in A.9.1

### **A.7.3 Historical Airline Passenger Operating Costs (\$/Year)**

=HistoricalAirlineTicketPrices\*HistoricalAirlineDemand  
 +HistoricalAncillaryFeeRevenue-HistoricalAirlineOperatingProfit



Historical Airline Ticket Prices is a variable covered in A.6.2

Historical Airline Demand is a variable covered in A.5.2

Historical Ancillary Fee Revenue is a variable covered in A.6.1

Historical Airline Operating Profit is a variable covered in A.10.3

## A.8 Wages

### A.8.1 Average Worker Compensation (dollars/Year/person)

$$= \int (\text{Change in Worker Compensation}) dt + [\text{Initial Worker Compensation}]$$

Description: This is the level of compensation including salary, bonus and benefits for the average airline industry worker

### Change in Worker Compensation (dollars/Year/person/Year)

$$= \text{Gap For Worker Compensation} / \text{Time to Change Worker Compensation}$$

Description:

### Gap For Worker Compensation (dollars/person/Year)

$$= \text{Indicated Compensation} - \text{Average Worker Compensation}$$

Description: Worker compensation will move toward the indicated level with some delay

### Indicated Compensation (dollars/Year/person)

$$= \text{Average Worker Compensation} * \text{Effect of Inflation in Worker Compensation}$$

\*Effect of Operating Margin on Worker Compensation

\*Effect of Outside Opportunities on Worker Compensation

\*Effect of Unemployment on Worker Compensation

\*Effect of Worker Tenure on Compensation

Description: Average worker compensation is pressured to change by a certain percentage. Each of the five effects modeled will indicate a certain percentage change, and their sum total effect will be the indicated change in compensation

- Average Worker Compensation is a variable covered in A.8.1

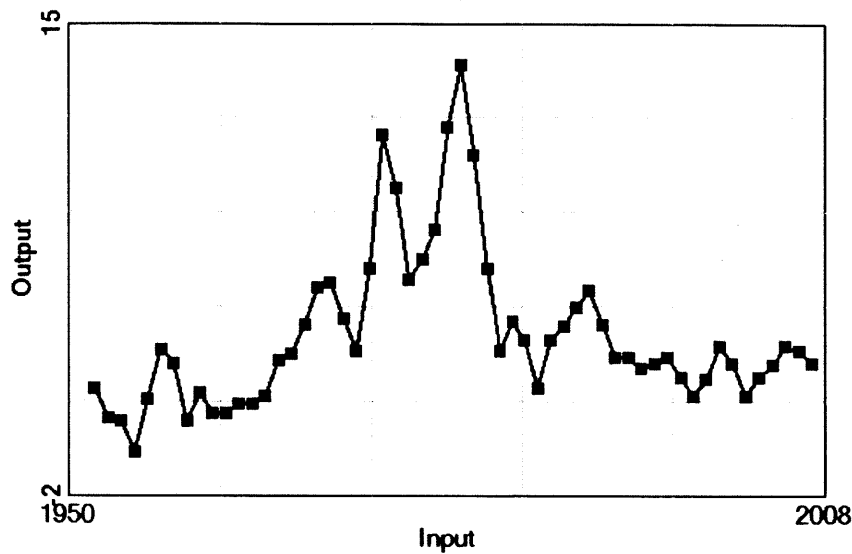
- Effect of Inflation in Worker Compensation (dmnl)

$$= 1 + \text{CPI Percentage Change} * \text{Strength of Inflation on Worker Compensation}$$

Description: The normal change in compensation per year all else equal This can be thought of as arising from inflation and other constant effects that would change compensation

$$- \text{CPI Percentage Change (dmnl/Year)}$$

$$= \text{CPI Data}(\text{Time}-1)/100$$



**Figure A-13: CPI Data**

Description: Data from the BLS on the Consumer Price Index, reported as the percentage change year on year of the average CPI during the year

\* CPI Data (dmnl/Year)

=[(1950,-2)-(2008,15)],(1952,1.9),(1953,0.8),(1954,0.7),(1955,-0.4)  
 ,(1956,1.5),(1957,3.3),(1958,2.8),(1959,0.7),(1960,1.7),(1961,1),(1962,1)  
 ,(1963,1.3),(1964,1.3),(1965,1.6),(1966,2.9),(1967,3.1),(1968,4.2)  
 ,(1969,5.5),(1970,5.7),(1971,4.4),(1972,3.2),(1973,6.2),(1974,11)  
 ,(1975,9.1),(1976,5.8),(1977,6.5),(1978,7.6),(1979,11.3),(1980,13.5)  
 ,(1981,10.3),(1982,6.2),(1983,3.2),(1984,4.3),(1985,3.6),(1986,1.9)  
 ,(1987,3.6),(1988,4.1),(1989,4.8),(1990,5.4),(1991,4.2),(1992,3)  
 ,(1993,3),(1994,2.6),(1995,2.8),(1996,3),(1997,2.3),(1998,1.6)  
 ,(1999,2.2),(2000,3.4),(2001,2.8),(2002,1.6),(2003,2.3)  
 ,(2004,2.7),(2005,3.4),(2006,3.2),(2007,2.8)

– Strength of Inflation on Worker Compensation (Year)

1

Description:

• Effect of Operating Margin on Worker Compensation (dmnl)

$$= \frac{(1 + \text{PerceivedMargin})}{(1 + \text{NormalMargin})} \text{Strength of Margin on Worker Compensation}$$

Description:

– Perceived Margin (dmnl)

=smoothi(((SwitchforHistoricalVariables)

\*HistoricalAirlineOperatingMargin+

(1-SwitchforHistoricalVariables)\*OperatingMargin)  
 ,MarginPerceptionDelay,InitialPercievedMargin)

Description: The margin currently affecting airline salaries is not the current margin, but rather recent margin, since it takes some time for the margin the airlines are experiencing to be perceived.

- \* Switch for Historical Variables is a variable covered in B.1.2
- \* Historical Airline Operating Margin is a variable covered in A.10.4
- \* Operating Margin is a variable covered in A.10.2
- \* Margin Perception Delay (years)

1

Description: It takes this long for maring to be perceived by unions and used in wage negotiations

- \* Initial Percieved Margin (dmnl)  
0.04

– Normal Margin (dmnl)  
0.068

Description:

– Strength of Margin on Worker Compensation (dmnl)  
0.425

Description: A measure of how responsive average worker compensation is to the presures from profit margin

● Effect of Outside Opportunities on Worker Compensation (dmnl)

=1+Max(WageRelativetoAverage

\*StrengthhofOutsideOpportunitiesonWorkerCompensation,-0.99)

Description: Outside opportunities and rising wages in other fields will force the airline industry to change its wages as well in order to attract the level of worker it needs

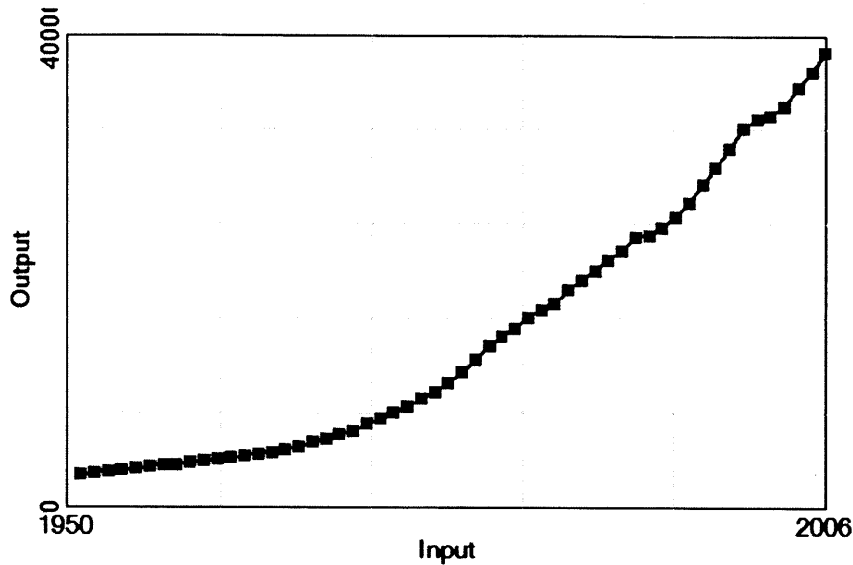
– Wage Relative to Average (dmnl)  
 =(NationalAverageWage-AverageWorkerCompensation)/  
 NationalAverageWage+WagePremiumforSkill

Description: The percentage difference between the national average wage and the wages of airline employees, adjusted up by the wage premium for skill

- \* National Average Wage (dollars/person/Year)  
 = NationalAverageWageData(Time-1)

Description: data from the social security administration on the national average wage

- National Average Wage Data (dollars/person/Year) shown in figure A-14



**Figure A-14: National Average Wage Data**

\* Average Worker Compensation is a variable covered in A.8.1

\* Wage Premium for Skill (dmnl)

1.2

Description: Each class of worker has particular skills or training that enable it to command higher wages than the average. Wages will still react to changes relative to the national average, but without this renormalization of the average wage our model would not have an equilibrium where pilots (for instance) made more than the average wage nationally.

– Strength of Outside Opportunities on Worker Compensation (dmnl)

0.75

Description:

• Effect of Unemployment on Worker Compensation (dmnl)

$= 1 + (\text{HistoricalUnemployment} - \text{NormalUnemployment})$

\*StrengthofUnemploymentEffectonWages

Description: Higher Unemployment will enable airlines to offer lower wages to their employees on average

– Historical Unemployment (dmnl)

$= \text{HistoricalUnemploymentData}(\text{Time}-1)/100$

Description: This is historical data on the unemployment rate in percentage of the labor force looking for work.

\* Historical Unemployment Data (dmnl) shown in figure A-15

**Figure A-15: Historical Unemployment Data**

- Normal Unemployment (dmnl)  
0.048  
Description: There is some normal level of unemployment at which there will be no effect of unemployment on wages
- Strength of Unemployment Effect on Wages (dmnl [0,40])  
10  
Description: While the Strength of the unemployment effect is an empirical matter these coefficients only make sense if they are negative.
- Effect of Worker Tenure on Compensation (dmnl)  
$$= (\text{AverageWorkerTenure} / \text{NormalWorkerTenure})^{\text{StrengthofTenureEffectonWages}}$$
  
Description: The pressure on wages from the length of service of the workforce
  - Average Worker Tenure is a variable covered in A.9.9
  - Normal Worker Tenure (years)  
14  
Description: A normalizing constant for the tenure effect on wages
  - Strength of Tenure Effect on Wages (dmnl)  
0.425  
Description: The strength of the effect of tenure on wages

**Average Worker Compensation is a variable covered in A.8.1**

**Time to Change Worker Compensation (years) 1**

Description: Workers only negotiate their wages sporadically, and so it takes time to wages to adjust to new conditions in the industry

**Initial Worker Compensation (dollars/(person\*Year))**

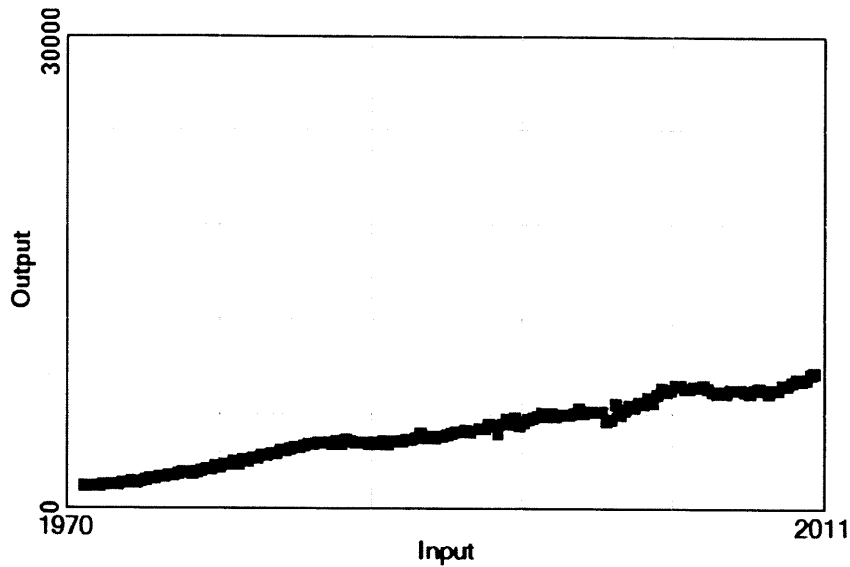
23090

Description: The initial average airline worker salary in 1977

**A.8.2 Historical Airline Salaries (dollars/person/Year)**

$$= \text{HistoricalAirlineSalaryData}(\text{Time}-1)$$

Description: Historical data on worker salaries



**Figure A-16: Historical Airline Salary Data**

**Historical Airline Salary Data (dollars/person/Year) shown in figure**

**A.8.3 Historical Real Wage (dollars/Year/person)**

$$= \text{HistoricalAirlineSalaries}/\text{CPI}$$

**Historical Airline Salaries is a variable covered in A.8.2**

**CPI is a variable covered in A.5.2**

**A.8.4 Historical Average Real Wage (dollars/Year/person)**

$$= \text{NationalAverageWage}/\text{CPI}$$

**National Average Wage is a variable covered in A.8.1**

**CPI is a variable covered in A.5.2**

**A.8.5 Simulated Real Wage (dollars/Year/person)**

$$= \text{AverageWorkerCompensation}/\text{CPI}$$

Average Worker Compensation is a variable covered in A.8.1

CPI is a variable covered in A.5.2

## A.9 Employees

### A.9.1 Rookie Employees (people)

$= \int (\text{Hiring} - \text{RookieLayoffs} - \text{SomeYearsofExperience}) dt + [\text{InitialEmployees}/4]$   
Description: The stock of newly hired employees

#### Hiring (people/Year)

$= \text{IndicatedHiring}/\text{TimetoHire}$   
Description: The flow of new hires into the air transportation industry

#### Indicated Hiring (people)

$= \text{Max}(\text{IndicatedAdjustmenttoWorkforce}, 0)$   
Description: Hiring is non-negative, so the max function ensures that only positive workforce adjustments cause hiring

#### Indicated Adjustment to Workforce (people)

$= \text{IndicatedTotalWorkforce} - \text{TotalWorkforce}$   
Description: The total change in the workforce indicated by airline capacity

- Indicated Total Workforce (people)

$= (\text{HistoricalAvailableSeatMiles} * \text{SwitchforHistoricalVariables} + (1 - \text{SwitchforHistoricalVariables}) * \text{AvailableSeatMiles}) / \text{AvaiableSeatMilesperEmployee}$

Description: The airline industry employs this many workers. This formulation assumes that there is a certain historically determined number of workers for every available seat mile of capacity.

- Historical Available Seat Miles is a variable covered in A.4.2
- Switch for Historical Variables is a variable covered in B.1.2
- Available Seat Miles is a variable covered in A.4.1
- Avaiable Seat Miles per Employee ((Seat\*mile/Year)/person)  
 $= \text{TableforASMperEmployee}(\text{Time}) * 1000$

Description: The available seat miles per employee is read from the observed historical data

\* Table for ASM per Employee ((Seat\*mile/Year)/person)  
 $= [ (1970, 0) - (2010, 4000) ], (1970, 1025), (1971, 1035.3), (1972, 1017.9), (1973, 1066.4), (1974, 1034.3), (1975, 1097.7), (1976, 1163.9), (1977, 1168), (1978, 1211.7), (1979, 1232.1), (1980, 1253.1), (1981, 1253.6)$

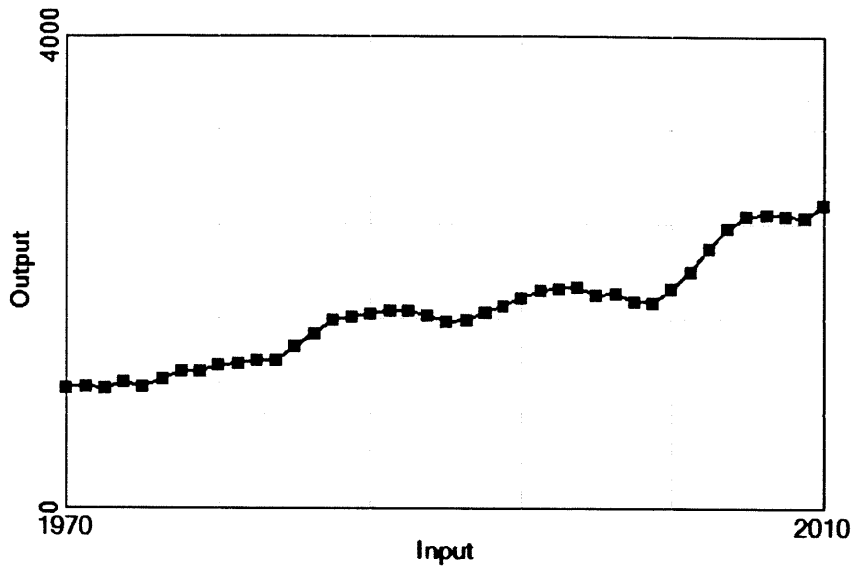


Figure A-17: Table for ASM per Employee

,(1982,1374.7),(1983,1485),(1984,1597.6),(1985,1627),(1986,1650.3)  
 ,(1987,1682.2),(1988,1680.9),(1989,1636.4),(1990,1585)  
 ,(1991,1598.8),(1992,1664.4),(1993,1722.9),(1994,1785.6)  
 ,(1995,1846),(1996,1868),(1997,1876.1),(1998,1808.5)  
 ,(1999,1824.8),(2000,1760.6),(2001,1748.2),(2002,1855)  
 ,(2003,2010.1),(2004,2208.3),(2005,2373.7),(2006,2477)  
 ,(2007,2497.5),(2008,2483.4),(2009,2463.6),(2010,2570.3)

Description: The historical values for seat miles per employee in thousands

- Total Workforce (people)

=RookieEmployees+EmployeeswithSomeExperience  
 +ExperiencedEmployees+VeryExperiencedEmployees

Description: The total workforce is the sum of each workforce stock.

- Rookie Employees is a variable covered in A.9.1
- Employees with Some Experience is a variable covered in A.9.2
- Experienced Employees is a variable covered in A.9.3
- Very Experienced Employees is a variable covered in A.9.4

**Time to Hire (Year)**

0.25

Description: The delay between when hiring is indicated and implemented.



### **Rookie Layoffs (people/Year)**

$$= \text{IndicatedLayoffs}/\text{TimetoExecuteLayoffs}/4$$

Description: The rate of layoffs from the indicated employee stock.

$$\text{Indicated Layoffs (people)} = -\text{Min}(\text{IndicatedAdjustmenttoWorkforce},0)$$

Description: Layoffs should only occur when the indicated adjustment to the workforce is negative. The additional sign change ensures that a negative indicated adjustment becomes a positive outflow from the stocks

**Indicated Adjustment to Workforce is a variable covered in A.9.1**

### **Time to Execute Layoffs (Year)**

0.125

Description: The delay between when layoffs are indicated and they begin to occur. Includes time to consider whether layoffs are justified.

### **Some Years of Experience (people/Year)**

$$= \text{RookieEmployees}/\text{DelayBetweenEmployeeExperienceStocks}$$

Description: An ageing flow of employees

**Rookie Employees is a variable covered in A.9.1**

### **Delay Between Employee Experience Stocks (years)**

8

Description:

### **Initial Employees (people)**

288980

Description:

## **A.9.2 Employees with Some Experience (people)**

$$= \int (\text{Some Years of Experience} - \text{More Years of Experience} - \text{Some Experience Layoffs}) dt + [\text{Initial Employees}/4]$$

Description: The stock of employees with some experience

**Some Years of Experience is a variable covered in A.9.1**

### **More Years of Experience (people/Year)**

$$= \text{EmployeeswithSomeExperience}/\text{DelayBetweenEmployeeExperienceStocks}$$

Description: An ageing flow of employees

**Employees with Some Experience is a variable covered in A.9.2**

**Delay Between Employee Experience Stocks is a variable covered in A.9.1**

**Some Experience Layoffs (people/Year)**

= IndicatedLayoffs/TimeToExecuteLayoffs/4

Description: The rate of layoffs from the indicated employee stock.

**Indicated Layoffs is a variable covered in A.9.1**

**Time to Execute Layoffs is a variable covered in A.9.1**

**Initial Employees is a variable covered in A.9.1**

**A.9.3 Experienced Employees (people)**

=  $\int (\text{MoreYearsofExperience} - \text{ExperiencedLayoffs} - \text{ManyYearsofExperience}) dt + [\text{InitialEmployees}/4]$

Description: The stock of employees with more experience

**More Years of Experience is a variable covered in A.9.2**

**Experienced Layoffs (people/Year)**

= IndicatedLayoffs/TimeToExecuteLayoffs/4

Description: The rate of layoffs from the indicated employee stock.

**Indicated Layoffs is a variable covered in A.9.1**

**Time to Execute Layoffs is a variable covered in A.9.1**

**Many Years of Experience (people/Year)**

= ExperiencedEmployees/DelayBetweenEmployeeExperienceStocks

Description: An ageing flow of employees

**Experienced Employees is a variable covered in A.9.3**

**Delay Between Employee Experience Stocks is a variable covered in A.9.1**

**Initial Employees is a variable covered in A.9.1**

#### **A.9.4 Very Experienced Employees (people)**

$$= \int (\text{Many Years of Experience} - \text{Retirement} - \text{Very Experienced Layoffs}) dt + [\text{Initial Employees}/4]$$

Description: The stock of employees with a large amount of experience

**Many Years of Experience is a variable covered in A.9.3**

#### **Retirement (people/Year)**

$$= \text{Very Experienced Employees} / \text{Delay Between Employee Experience Stocks}$$

Description: An ageing flow of employees

**Very Experienced Employees is a variable covered in A.9.4**

**Delay Between Employee Experience Stocks is a variable covered in A.9.1**

#### **Very Experienced Layoffs (people/Year)**

$$= \text{Indicated Layoffs} / \text{Time to Execute Layoffs} / 4$$

Description: The rate of layoffs from the indicated employee stock.

**Indicated Layoffs is a variable covered in A.9.1**

**Time to Execute Layoffs is a variable covered in A.9.1**

**Initial Employees is a variable covered in A.9.1**

#### **A.9.5 Total Years of Rookie Tenure (person\*years)**

$$= \int (\text{Tenure Gain 1} - \text{Layoff Loss 1} - \text{Tenure Transfer 1}) dt + [(0.5) * \text{Delay Between Employee Experience Stocks} * \text{Initial Employees} / 4]$$

Description: A coflow stock of total experience

#### **Tenure Gain 1 (person\*Year/Year)**

$$= \text{Rookie Employees} * \text{Years of Tenure Gained per Employee per Year}$$

Description: The rate of flow of experience from normal work

**Rookie Employees is a variable covered in A.9.1**

**Years of Tenure Gained per Employee per Year**  
(person\*Year/person/Year)

1

Description: The rate of experience gain from one years work is one person year per person per year, which is dimensionless

**Layoff Loss 1 (person\*years/Year)**

= AverageTenure1\*RookieLayoffs

Description: The loss of tenure from layoffs for the indicated stock

**Average Tenure 1 (years)**

= Total Years of Rookie Tenure/Rookie Employees

Description: The average experience of rookies

**Total Years of Rookie Tenure is a variable covered in A.9.5**

**Rookie Employees is a variable covered in A.9.1**

**Rookie Layoffs is a variable covered in A.9.1**

**Tenure Transfer 1 (person\*Year/Year)**

= Average Tenure 1\*Some Years of Experience

Description: A flow of experience through the coflow

**Average Tenure 1 is a variable covered in A.9.5**

**Some Years of Experience is a variable covered in A.9.1**

**Delay Between Employee Experience Stocks is a variable covered in A.9.1**

**Initial Employees is a variable covered in A.9.1**

**A.9.6 Total Years of Some Experience Tenure (person\*years)**

=  $\int (\text{TenureGain2} + \text{TenureTransfer1} - \text{LayoffLoss2} - \text{TenureTransfer2}) dt +$   
(1.5)\*DelayBetweenEmployeeExperienceStocks\*InitialEmployees/4

Description: A coflow stock of total experience

**Tenure Gain 2 (person\*Year/Year)**

= EmployeeswithSomeExperience\*YearsofTenureGainedperEmployeeperYear

Description: The rate of flow of experience from normal work

**Employees with Some Experience is a variable covered in A.9.2**

**Years of Tenure Gained per Employee per Year is a variable covered in A.9.5**

**Tenure Transfer 1 is a variable covered in A.9.5**

**Layoff Loss 2 (person\*years/Year)**

= AverageTenure2\*SomeExperienceLayoffs

Description: The loss of tenure from layoffs for the indicated stock

**Average Tenure 2 (years)**

= TotalYearsofSomeExperienceTenure/EmployeeewithSomeExperience

Description: The average experience of employees with some experience

**Total Years of Some Experience Tenure is a variable covered in A.9.6**

**Employees with Some Experience is a variable covered in A.9.2**

**Some Experience Layoffs is a variable covered in A.9.2**

**Tenure Transfer 2 (person\*Year/Year)**

= MoreYearsofExperience\*AverageTenure2

Description: A flow of experience through the coflow

**More Years of Experience is a variable covered in A.9.2**

**Average Tenure 2 is a variable covered in A.9.6**

**Delay Between Employee Experience Stocks is a variable covered in A.9.1**

**Initial Employees is a variable covered in A.9.1**

**A.9.7 Total Years of Experienced Tenure (person\*years)**

=  $\int (\text{TenureGain3} + \text{TenureTransfer2} - \text{LayoffLoss3} - \text{TenureTransfer3}) dt + (2.5) * \text{DelayBetweenEmployeeExperienceStocks} * \text{InitialEmployees} / 4$

Description: A coflow stock of total experience

**Tenure Gain 3 (person\*Year/Year)**

= ExperiencedEmployees\*YearsofTenureGainedperEmployeeperYear

Description: The rate of flow of experience from normal work

**Experienced Employees is a variable covered in A.9.3**

**Years of Tenure Gained per Employee per Year is a variable covered in A.9.5**

**Tenure Transfer 2 is a variable covered in A.9.6**

**Layoff Loss 3 (person\*years/Year)**

= AverageTenure3\*ExperiencedLayoffs

Description: The loss of tenure from layoffs for the indicated stock

**Average Tenure 3 (years)**

= TotalYearsofExperiencedTenure/ExperiencedEmployees

Description: The average experience of experienced employees

**Total Years of Experienced Tenure is a variable covered in A.9.9**

**Experienced Employees is a variable covered in A.9.3**

**Experienced Layoffs is a variable covered in A.9.3**

**Tenure Transfer 3 (person\*Year/Year)**

= AverageTenure3\*ManyYearsofExperience

Description: A flow of experience through the coflow

**Average Tenure 3 is a variable covered in A.9.7**

**Many Years of Experience is a variable covered in A.9.3**

**Delay Between Employee Experience Stocks is a variable covered in A.9.1**

**Initial Employees is a variable covered in A.9.1**

**A.9.8 Total Years of Very Experienced Tenure (person\*years)**

=  $\int (\text{TenureGain4} + \text{TenureTransfer3} - \text{LayoffLoss4} - \text{RetirementTenureLoss}) dt$

+ (3.5)\*DelayBetweenEmployeeExperienceStocks\*InitialEmployees/4

Description: A coflow stock of total experience

**Tenure Gain 4 (person\*Year/Year)**

= VeryExperiencedEmployees\*YearsofTenureGainedperEmployeeperYear

Description: The rate of flow of experience from normal work

**Very Experienced Employees is a variable covered in A.9.4**

**Years of Tenure Gained per Employee per Year is a variable covered in A.9.5**

**Tenure Transfer 3 is a variable covered in A.9.7**

**Layoff Loss 4 (person\*years/Year)**

= AverageTenure4\*VeryExperiencedLayoffs

Description: The loss of tenure from layoffs for the indicated stock

**Average Tenure 4 (years)**

= TotalYearsofVeryEperiencedTenure/VeryExperiencedEmployees

Description: The average experience of the most experienced employees

**Total Years of Very Experienced Tenure is a variable covered in A.9.8**

**Very Experienced Employees is a variable covered in A.9.4**

**Very Experienced Layoffs is a variable covered in A.9.4**

**Retirement Tenure Loss (person\*Year/Year)**

= AverageTenure4\*Retirement

Description: A flow of experience through the coflow

**Average Tenure 4 is a variable covered in A.9.8**

**Retirement is a variable covered in A.9.4**

**Delay Between Employee Experience Stocks is a variable covered in A.9.1**

**Initial Employees is a variable covered in A.9.1**

**A.9.9 Average Worker Tenure (years)**

= Total Years of Experience/Total Workforce

Description: The average experience of all workers in the industry

**Total Years of Experience (person\*years)**

=Total Years of Rookie Tenure+Total Years of Some Experience Tenure

+Total Years of Experienced Tenure+Total Years of Very Experienced Tenure

Description: The sum total of all person years of worker experience in the industry

**Total Years of Rookie Tenure is a variable covered in A.9.5**

**Total Years of Some Experience Tenure is a variable covered in A.9.6**

**Total Years of Experienced Tenure is a variable covered in A.9.9**

**Total Years of Very Experienced Tenure is a variable covered in A.9.8**

**Total Workforce is a variable covered in A.9.1**

## **A.10 Operating Profit**

### **A.10.1 Operating Profit (dollars/Year)**

**= OperatingRevenue-TotalOperatingCosts**

Description:

#### **Operating Revenue (dollars/Year)**

**= PassengerRevenue+HistoricalAncillaryFeeRevenue**

Description: Revenue from passenger travel added to revenue from all other fees is the models total operating revenue

#### **Passenger Revenue (dollars/Year)**

**= RevenueSeatMiles\*TicketPrice**

Description:

#### **Revenue Seat Miles (Seat\*miles/Year)**

**= AvailableSeatMiles\*LoadFactor**

Description: These are the revenue generating seat miles that the airlines fly

- Available Seat Miles is a variable covered in A.4.1

- Load Factor is a variable covered in A.4.1

**Ticket Price is a variable covered in A.6.1**

**Historical Ancillary Fee Revenue is a variable covered in A.6.1**

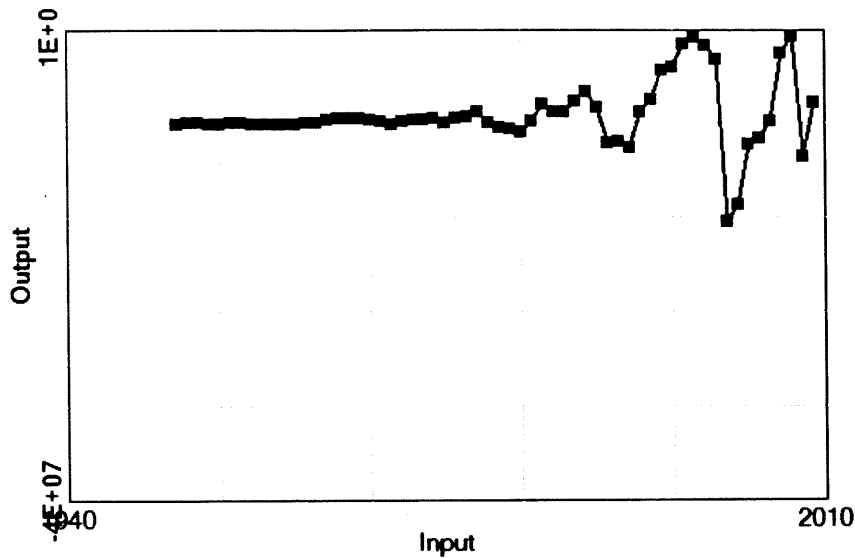
**Total Operating Costs is a variable covered in A.7.2**

### **A.10.2 Operating Margin (fraction)**

**= ZIDZ(OperatingProfit,PassengerRevenue)**

Description: The percentage profit of the airline industry





**Figure A-18: Table for Historical Airline Operating Profit**

**Operating Profit is a variable covered in A.10.1**

**Passenger Revenue is a variable covered in A.10.1**

### **A.10.3 Historical Airline Operating Profit (dollars/Year)**

**= TableforHistoricalAirlineOperatingProfit(Time-1)\*1000**

**Description: The actual airline industry operating profit**

#### **Table for Historical Airline Operating Profit (dollars/Year)**

**=[(1940,-4e+007)-(2010,1e+007)],(1950,75990),(1951,127624),(1952,195167),  
,(1953,106336),(1954,124375),(1955,142624),(1956,134890),(1957,65005)  
,(1958,107512),(1959,122349),(1960,77591),(1961,20059),(1962,189999)  
,(1963,279787),(1964,470097),(1965,671928),(1966,775497),(1967,708194)  
,(1968,504888),(1969,391931),(1970,43031),(1971,328475),(1972,584470)  
,(1973,585266),(1974,725740),(1975,127879),(1976,721933),(1977,908040)  
,(1978,1.36486e+006),(1979,199055),(1980,-221615),(1981,-454800)  
,(1982,-733435),(1983,310410),(1984,2.15151e+006),(1985,1.42626e+006)  
,(1986,1.3231e+006),(1987,2.46889e+006),(1988,3.4365e+006)  
,(1989,1.81127e+006),(1990,-1.91234e+006),(1991,-1.78474e+006)  
,(1992,-2.44446e+006),(1993,1.43817e+006),(1994,2.71346e+006)  
,(1995,5.85952e+006),(1996,6.20907e+006),(1997,8.58679e+006)  
,(1998,9.32781e+006),(1999,8.40331e+006),(2000,6.99893e+006)  
,(2001,-1.03259e+007),(2002,-8.56641e+006),(2003,-2.092e+006)  
,(2004,-1.489e+006),(2005,447000),(2006,7.639e+006),(2007,9.343e+006)  
,(2008,-3.35e+006),(2009,2.33e+006)**

Description: This is the data for actual airline operating profits by year since 1950 in reported thousands of dollars

#### **A.10.4 Historical Airline Operating Margin (fraction)**

$$= \text{HistoricalAirlineOperatingProfit} / (\text{HistoricalAirlineDemand} * \text{HistoricalAirlineTicketPrices})$$

Description: The operating margin experienced by the industry historically

**Historical Airline Operating Profit is a variable covered in A.10.3**

**Historical Airline Demand is a variable covered in A.5.2**

**Historical Airline Ticket Prices is a variable covered in A.6.2**

### **A.11 September 11th Shock**

#### **A.11.1 9/11 Effect On Demand (dmnl)**

$$= \int (\text{Reduction of 9/11 Effect on Demand} - \text{Decrease in Demand from 9/11}) dt + 1$$

Description: The adjustment of total demand arising from the 9/11 attacks

#### **Reduction of 9/11 Effect on Demand (1/Year)**

$$= (\text{Normal 9/11 Effect on Demand} - \text{9/11 Effect On Demand}) / \text{Public Perception of Terrorism Decay Time}$$

Description: The readjustment of the effect of 9/11 on demand results from the public adjusting their conception of the likelihood of terrorism

#### **Normal 9/11 Effect on Demand (dmnl)**

1

Description: Normally there is no effect of 9/11 on demand, so the goal for the stock should be 1.

**9/11 Effect On Demand is a variable covered in A.11.1**

#### **Public Perception of Terrorism Decay Time (years)**

4.25

Description: The length of the delay in the public's adjustment of their perception of terrorism

#### **Decrease in Demand from 9/11 (1/Year)**

$$= \text{9/11 Exogenous Terrorism Shock} / \text{Length of 9/11 Effect}$$

Description: A decrease in the terrorism effect on demand corresponding to the effect of the 9/11 attacks.

### **9/11 Exogenous Terrorism Shock (dmnl)**

$$=(\text{IFTHENELSE}(\text{Time} > 2001.13,1,0)+\text{IFTHENELSE}(\text{Time} > (2001.13+\text{Lengthof9/11Effect}),-1,0))*\text{Sizeof9/11Effect}$$

Description: A formulation that causes the 9/11 effect to start on 9/11 and stop a set number of years later

**Length of 9/11 Effect (years)** 0.5

Description: The period of time over which the 9/11 effect on demand acts

**Size of 9/11 Effect (dmnl)** 0.185

Description: The total percentage reduction in demand due to the 9/11 attacks, as estimated from historical data.

Length of 9/11 Effect is a variable covered in A.11.1

## **A.12 Data Reporting**

### **A.12.1 Reported Variable (dollars/Year)**

$$= \text{DrainedReportedVariable}[\text{Data}] * \text{TIMESTEP} / \text{ReportingPeriod}$$

#### **Drained Reported Variable (dollars/Year)**

$$= \text{IFTHENELSE}(\text{checkreporting}[\text{Data}] = 0, \text{AccumulatedReportedVariable}[\text{Data}] / \text{TIMESTEP}, 0)$$

#### **Check reporting (Year)**

$$\text{Checkreporting}[\text{Data}] = \text{MODULO}(\text{Time}, \text{ReportingPeriod})$$

**Reporting Period (Year)** 1

#### **Accumulated Reported Variable (dollars)**

$$= \int (\text{NewReportedVariable}[\text{Data}] - \text{DrainedReportedVariable}[\text{Data}]) dx + 0$$

Description: The reporting process creates a delay between when the money was actually made by the industry and when the profits are reported to investors

#### **New Reported Variable (dollars/Year)**

- $\text{NewReportedVariable}[\text{Profit}] = \text{OperatingProfit}$   
Operating Profit is a variable covered in A.10.1
- $\text{NewReportedVariable}[\text{Costs}] = \text{TotalOperatingCosts}$   
Total Operating Costs is a variable covered in A.7.2

- $\text{NewReportedVariable}[\text{Prices}] = \text{TicketPrice} * \text{UnitEquiv2}$   
 Ticket Price is a variable covered in A.6.1  
 Unit Equiv 2  $((\text{Seat} * \text{miles}) / \text{Year})$ 
  - 1
  - Description: converts \$/seat mile into \$/year
- $\text{NewReportedVariable}[\text{Demand}] = \text{ActualDemandForSeatMiles} * \text{UnitEquiv1}$   
 Actual Demand For Seat Miles is a variable covered in A.5.1  
 Unit Equiv 1  $(\$ / (\text{Seat} * \text{mile}))$ 
  - 1
  - Description: converts seat miles per year into dollars per year
- $\text{NewReportedVariable}[\text{Capacity}] = \text{AvailableSeatMiles} * \text{UnitEquiv1}$   
 Available Seat Miles is a variable covered in A.4.1  
 Unit Equiv 1 is a variable covered in A.12.1
- $\text{NewReportedVariable}[\text{Salary}] = \text{AverageWorkerCompensation} * \text{UnitsEquiv3}$   
 Average Worker Compensation is a variable covered in A.8.1  
 Units Equiv 3 (person)
  - 1
  - Description: converts dollars per person per year into dollars per year

Description: Reported Variables fill a stock that averages their values over the reporting period

**Drained Reported Variable is a variable covered in A.12.1**

**Reporting Period is a variable covered in A.12.1**

# Appendix B

## Documentation of the Insurance Industry Model

### B.1 Demand for Insurance

#### B.1.1 New Underwriting (dollars/Year)

=  $\text{MAX}(\text{Underwriting Renewal} + \text{Adjustment for Desired Insurance}, 0)$

Description: The flow of new underwriting in the industry

#### Underwriting Renewal (\$/Year)

= Underwriting Outflow

Underwriting Outflow is covered in section B.2.3.

#### Adjustment for Desired Insurance (dollars/Year)

=  $\text{Gap in Desired Insurance} / \text{Desired Insurance Adjustment Time}$

Description: The rate at which desired insurance is being underwritten, may be negative if the level of insurance desired is lower than the current level

#### Gap in Desired Insurance (dollars)

=  $\text{Desired Insurance} - \text{Total Underwriting Exposure}$

Description: The difference between the amount of insurance desired after considering the preferences of the consumer, the desires of the industry and the level of assets in the economy.

#### Desired Insurance (dollars)

= Consumer Desired Insurance

- Consumer Desired Insurance (dollars)

=  $(\text{Proxy for Insurable Assets}) * \text{Effect of Premiums on Demand for Insurance}$

Description: The level of underwriting desired by the consumer after considering the value of assets in the economy, the fraction of those assets normally insured and the effect of current premiums on the demand for insurance.

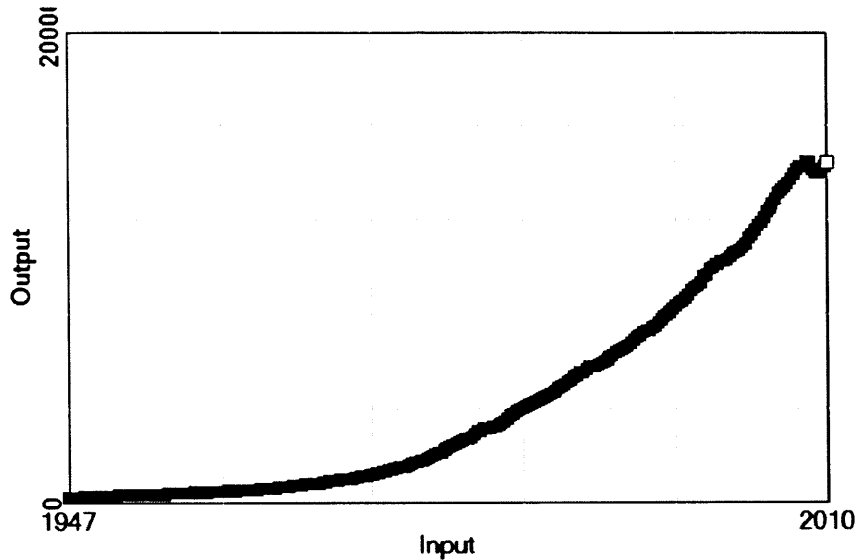
- Proxy for Insurable Assets (dollars)
  - = Stock of Capital\*Fraction of Assets Desiring Insurance
  - \* Stock of Capital (dollars)
    - =  $\int(\text{GDP Investment}-\text{Abandonment of Capital})dt + [\text{GDP Investment}*\text{Insurable Life of Capital}]$
  - \* GDP Investment is covered in section B.1.2.
  - \* Abandonment of Capital (dollars/Year)
    - = Stock of Capital/Insurable Life of Capital
  - \* Insurable Life of Capital (years)
    - 14
  - \* Fraction of Assets Desiring Insurance (dmnl)
    - = Income Effect on Insurance Demand\*Normal Fraction of Assets Desiring Insurance
  - \* Income Effect on Insurance Demand (dmnl)
    - =  $(\text{GDP Simulated}/\text{Reference Income})^{\text{Income Elasticity of Demand}}$
    - GDP Simulated is covered in B.1.2.
    - Reference Income (dollars/Year)
      - = Initial(GDP Simulated)
    - Income Elasticity of Demand (dmnl)
      - 0.453
  - \* Normal Fraction of Assets Desiring Insurance (dmnl)
    - 0.0408
- Effect of Premiums on Demand for Insurance (dmnl)
  - =  $(\text{Current Premium per unit Exposure}/\text{Initial Premium})^{\text{Price Elasticity of Demand}}$
  - \* Current Premium per unit Exposure is covered in section B.7.1
  - \* Initial Premium is covered in section B.7.1
  - \* Price Elasticity of Demand (dmnl)
    - 1.5

### **Total Underwriting Exposure is covered in section B.2.3**

#### **Desired Insurance Adjustment Time (Year)**

5.11

Description: The time it takes consumers and insurance companies to adjust the level of insurance towards the current stock of insurance



**Figure B-1:** Table for Historical GDP

### B.1.2 GDP Investment (dollars/Year)

= GDP Simulated\*GDP Investment Fraction

#### GDP Simulated (dollars/Year)

= GDP\*IF THEN ELSE(Switch for Impulse Response=1, 1 , (1-Switch for Historical GDP) )+IF THEN ELSE(Switch for Impulse Response=1, 0 , Switch for Historical GDP)\*Historical GDP

Description: The current GDP being used in the simulation

#### Switch for Historical GDP (dmnl) 1

Description: Controls whether the model uses historical or stochastic GDP

#### Switch for Impulse Response (dmnl) 0

#### Historical GDP (dollars/Year)

= Table for Historical GDP(Time)\*1000000000

Description: The nominal GDP experienced historically

#### Table for Historical GDP (dollars/Year)

=[(1960,0)-(2010,20000)],(1960,527),(1960.25,526.2),(1960.5,529),  
 (1960.75,523.7),(1961,528),(1961.25,539),(1961.5,549.5),(1961.75,562.6),  
 (1962,576.1),(1962.25,583.2),(1962.5,590),(1962.75,593.3),(1963,602.5),  
 (1963.25,611.2),(1963.5,623.9),(1963.75,633.5),(1964,649.6),  
 (1964.25,658.9),(1964.5,670.5),(1964.75,675.6),(1965,695.7),

(1965.25,708.1),(1965.5,725.2),(1965.75,747.5),(1966,770.8),  
(1966.25,779.9),(1966.5,793.1),(1966.75,806.9),(1967,817.8),  
(1967.25,822.3),(1967.5,837),(1967.75,852.7),(1968,879.8),  
(1968.25,904.1),(1968.5,919.3),(1968.75,936.2),(1969,960.9),  
(1969.25,976.1),(1969.5,996.3),(1969.75,1004.5),(1970,1017.1),  
(1970.25,1033.1),(1970.5,1050.5),(1970.75,1052.7),(1971,1098.1),  
(1971.25,1118.8),(1971.5,1139.1),(1971.75,1151.4),(1972,1190.1),  
(1972.25,1225.6),(1972.5,1249.3),(1972.75,1286.6),(1973,1335.1),  
(1973.25,1371.5),(1973.5,1390.7),(1973.75,1431.8),(1974,1446.5),  
(1974.25,1484.8),(1974.5,1513.7),(1974.75,1552.8),(1975,1569.4),  
(1975.25,1605),(1975.5,1662.4),(1975.75,1713.9),(1976,1771.9),  
(1976.25,1804.2),(1976.5,1837.7),(1976.75,1884.5),(1977,1938.5),  
(1977.25,2005.2),(1977.5,2066),(1977.75,2110.8),(1978,2149.1),  
(1978.25,2274.7),(1978.5,2335.2),(1978.75,2416),(1979,2463.3),  
(1979.25,2526.4),(1979.5,2599.7),(1979.75,2659.4),(1980,2724.1),  
(1980.25,2728),(1980.5,2785.2),(1980.75,2915.3),(1981,3051.4),  
(1981.25,3084.3),(1981.5,3177),(1981.75,3194.7),(1982,3184.9),  
(1982.25,3240.9),(1982.5,3274.4),(1982.75,3312.5),(1983,3381),  
(1983.25,3482.2),(1983.5,3587.1),(1983.75,3688.1),(1984,3807.4),  
(1984.25,3906.3),(1984.5,3976),(1984.75,4034),(1985,4117.2),  
(1985.25,4175.7),(1985.5,4258.3),(1985.75,4318.7),(1986,4382.4),  
(1986.25,4423.2),(1986.5,4491.3),(1986.75,4543.3),(1987,4611.1),  
(1987.25,4686.7),(1987.5,4764.5),(1987.75,4883.1),(1988,4948.6),  
(1988.25,5059.3),(1988.5,5142.8),(1988.75,5251),(1989,5360.3),  
(1989.25,5453.6),(1989.5,5532.9),(1989.75,5581.7),(1990,5708.1),  
(1990.25,5797.4),(1990.5,5850.6),(1990.75,5846),(1991,5880.2),  
(1991.25,5962),(1991.5,6033.7),(1991.75,6092.5),(1992,6190.7),  
(1992.25,6295.2),(1992.5,6389.7),(1992.75,6493.6),(1993,6544.5),  
(1993.25,6622.7),(1993.5,6688.3),(1993.75,6813.8),(1994,6916.3),  
(1994.25,7044.3),(1994.5,7131.8),(1994.75,7248.2),(1995,7307.7),  
(1995.25,7355.8),(1995.5,7452.5),(1995.75,7542.5),(1996,7638.2),  
(1996.25,7800),(1996.5,7892.7),(1996.75,8023),(1997,8137),  
(1997.25,8276.8),(1997.5,8409.9),(1997.75,8505.7),(1998,8600.6),  
(1998.25,8698.6),(1998.5,8847.2),(1998.75,9027.5),(1999,9148.6),  
(1999.25,9252.6),(1999.5,9405.1),(1999.75,9607.7),(2000,9709.5),  
(2000.25,9949.1),(2000.5,10017.5),(2000.75,10129.8),(2001,10165.1),  
(2001.25,10301.3),(2001.5,10305.2),(2001.75,10373.1),(2002,10498.7),  
(2002.25,10601.9),(2002.5,10701.7),(2002.75,10766.9),(2003,10888.4),  
(2003.25,11008.1),(2003.5,11255.7),(2003.75,11416.5),(2004,11597.2),  
(2004.25,11778.4),(2004.5,11950.5),(2004.75,12144.9),(2005,12379.5),  
(2005.25,12516.8),(2005.5,12741.6),(2005.75,12915.6),(2006,13183.5),  
(2006.25,13347.8),(2006.5,13452.9),(2006.75,13611.5),(2007,13789.5),  
(2007.25,14008.2),(2007.5,14158.2),(2007.75,14291.3),(2008,14328.4),  
(2008.25,14471.8),(2008.5,14484.9),(2008.75,14191.2),(2009,14049.7),  
(2009.25,14034.5),(2009.5,14114.7),(2009.75,14277.3),(2010,14446.4),



(2010.25,14578.7),(2010.5,14745.1),(2010.75,14870.4)

Description: Historical Nominal GDP

### **GDP (dollars/Year)**

= Function for GDP\*GDP Random Noise Output\*(1-Switch for Impulse Response)+Switch for Impulse Response\*GDP Pulse

Description: The US gross domestic product

### **Function for GDP (dollars/Year)**

= Initial GDP\*EXP(Growth Rate of GDP\*(Time-Initial Time))

- Initial GDP (dollars/Year)

1

Description: The size of GDP at the beginning of the long horizon stochastic model run

- Growth Rate of GDP (dmnl/Year)

0.057

Description: The fractional percentage growth rate of GDP for long horizon tests

### **GDP Random Noise Output**

#### **GDP Pulse (dollars/Year)**

= (1+Pulse(Initial Time+10, 0)/Time STEP)\*One Dollar

- One Dollar (dollar)

1

Description: One dollar is used as the level of GDP for the impulse response tests.

### **GDP Investment Fraction (dmnl)**

0.125

## **B.2 Underwriting**

### **B.2.1 Premium per Dollar of Underwriting (dmnl/Year)**

= Total Premiums/Total Underwriting Exposure

Description: The fraction of every underwritten dollar collected as premiums each year

## **B.2.2 Total Premiums (dollars/Year)**

= Recent Premiums+Older Premiums+Oldest Premiums

Description: The sum of all premiums paid to the industry each year

### **Recent Premiums (dollars/Year)**

=  $\int$  (Premium Inflow-Recent to Older Premium Flow) dt + [Initial Premium\*Initial Dollars Underwritten per Stage]

Description: The first stock of total premiums collected by the industry

### **Premium Inflow (dollars/Year/Year)**

= Current Premium per unit Exposure\*Underwriting Inflow

Description: total premiums collected each year enter the aging chain at the current premium per dollar of underwriting

**Current Premium per unit Exposure is covered in section B.7.1.**

**Underwriting Inflow is covered in section B.2.3.**

### **Recent to Older Premium Flow (dollars/Year/Year)**

= Average Recent Premiums\*Recent to Older Underwriting Flow

Description: The flow of premiums from one stock in the aging chain to another is assumed to occur at the average level of the stock.

### **Average Recent Premiums (dmnl/Year)**

= Recent Premiums/Recent Dollars Underwritten

Description: The average cents on the dollar of premiums paid for recent underwriting

• Recent Dollars Underwritten is covered in section B.2.3.

**Recent to Older Underwriting Flow is covered in section B.2.3.**

**Initial Premium is covered in section B.7.1.**

**Initial Dollars Underwritten per Stage is covered in section B.2.3.**

### **Older Premiums (dollars/Year)**

=  $\int$  (Recent to Older Premium Flow-Older to Oldest Premium Flow) dt + [Initial Premium\*Initial Dollars Underwritten per Stage]

Description: The second stock of total premiums collected by the industry

**Recent to Older Premium Flow is covered in section B.2.2.**

**Older to Oldest Premium Flow (dollars/Year/Year)**

= Average Older Premiums\*Older to Oldest Underwriting Flow

Description: The flow of premiums from one stock in the aging chain to another is assumed to occur at the average level of the stock.

**Average Older Premiums (dmnl/Year)** = Older Premiums/Older Dollars Underwritten

Description: The average cents on the dollar of premiums paid for older underwriting

- Older Dollars Underwritten is covered in section B.2.3.

**Older to Oldest Underwriting Flow is covered in section B.2.3.**

**Oldest Premiums (dollars/Year)**

=  $\int$  (Older to Oldest Premium Flow-Premium Outflow) dt + [Initial Premium\*Initial Dollars Underwritten per Stage]

Description: The third stock of total premiums collected by the industry

**Older to Oldest Premium Flow is covered in section B.2.2.**

**Premium Outflow (dollars/(Year\*Year))**

= Average Oldest Premiums\*Underwriting Outflow

Description: The flow of premiums from one stock in the aging chain to another is assumed to occur at the average level of the stock.

**Average Oldest Premiums (dmnl/Year)**  
= Oldest Premiums/Oldest Dollars Underwritten

Description: The average cents on the dollar of premiums paid for the oldest underwriting

- Oldest Dollars Underwritten is covered in section B.2.3.

**Underwriting Outflow is covered in section B.2.3.**

**B.2.3 Total Underwriting Exposure (dollars)**

= Recent Dollars Underwritten+Oldest Dollars Underwritten+Older Dollars Underwritten

Description: The sum of each underwriting stock in the aging chain

**Recent Dollars Underwritten (dollars)**

=  $\int$  (Underwriting Inflow-Recent to Older Underwriting Flow) dt + [Initial Dollars Underwritten per Stage]

Description: The first stage of underwriting

**Underwriting Inflow (dollars/Year)**

= New Underwriting

New Underwriting is covered in section B.1.1.

**Recent to Older Underwriting Flow (dollars/Year)**

= Recent Dollars Underwritten/per Stage Underwriting Term

Description: aging of underwriting flow

**Per Stage Underwriting Term (years)**

= Average Underwriting Term/Underwriting Delay Order

Description: Each stage of the underwriting stock flow chain will have an equal delay length

- Average Underwriting Term (years)

1

Description: The average term of an insurance policy

- Underwriting Delay Order (dmnl)

3

Description: The number of stocks in the disaggregate underwriting structure.

**Initial Dollars Underwritten per Stage (dollars)**

= Initial Dollars Underwritten/Underwriting Delay Order

Description: Each stage of the underwriting stock flow chain will start with an equal share of the initial underwriting

**Initial Dollars Underwritten (dollars)**

= Initial(Fraction of Assets Desiring Insurance\*GDP Simulated\*Insurable Life of Capital\*GDP Investment Fraction)

Description: The initial level of underwriting is set so that the model will start in dynamic equilibrium

- Fraction of Assets Desiring Insurance is covered in section B.1.1.
- GDP Simulated is covered in section B.1.2.
- Insurable Life of Capital is covered in section B.1.1.
- GDP Investment Fraction is covered in section B.1.2.

### **Older Dollars Underwritten (dollars)**

$$= \int (\text{Recent to Older Underwriting Flow} - \text{Older to Oldest Underwriting Flow}) dt + [\text{Initial Dollars Underwritten per Stage}]$$

Description: The second stage of underwriting

**Recent to Older Underwriting Flow is covered in section B.2.3.**

### **Older to Oldest Underwriting Flow (dollars/Year)**

$$= \text{Older Dollars Underwritten/per Stage Underwriting Term}$$

Description: The second aging chain flow of underwriting

**Per Stage Underwriting Term is covered in section B.2.3.**

**Initial Dollars Underwritten per Stage is covered in section B.2.3.**

### **Oldest Dollars Underwritten (dollars)**

$$= \int (\text{Older to Oldest Underwriting Flow} - \text{Underwriting Outflow}) dt + [\text{Initial Dollars Underwritten per Stage}]$$

Description: The last stage of underwriting

**Older to Oldest Underwriting Flow is covered in section B.2.3.**

### **Underwriting Outflow (dollars/Year)**

$$= \text{Oldest Dollars Underwritten/per Stage Underwriting Term}$$

Description: The expiration of underwriting contracts.

**Per Stage Underwriting Term is covered in section B.2.3.**

## **B.3 Underwriting Loss Aging Chain**

### **B.3.1 Normal Claims Incurred (dollars/Year)**

$$= \text{Expected Casualty Rate of Recent Underwriting} + \text{Expected Casualty Rate of Older Underwriting} + \text{Expected Casualty Rate of Oldest Underwriting}$$

Description: Only a small fraction of all policies generate a claim each year

### **B.3.2 Expected Casualty Rate of Recent Underwriting (dollars/Year)**

$$= \int (\text{Expected Casualty Rate Inflow} - \text{Recent to Older Expected Casualty Rate Flow}) dt + [\text{Underwriting Expected Casualty Rate} * \text{Initial Dollars Underwritten per Stage}]$$

Description: A measure of the total claims generated by the recent pool of underwriting per year

**Expected Casualty Rate Inflow (dollars/Year/Year)**

= New Underwriting\*Underwriting Expected Casualty Rate

Description: The inflow of claim generating underwriting policies.

**New Underwriting is covered in section B.1.1.**

**Underwriting Expected Casualty Rate is covered in section B.4.1.**

**Recent to Older Expected Casualty Rate Flow (dollars/(Year\*Year))**

= Average Expected Casualty Rate of Recent Underwriting\*Recent to Older Underwriting Flow

Description: The aging of claim generating policies

**Average Expected Casualty Rate of Recent Underwriting (dmnl/Year)**

= Expected Casualty Rate of Recent Underwriting/Recent Dollars Underwritten

Description: The fraction of all recent underwriting that will generate a claim this year

**Recent Dollars Underwritten is covered in section B.2.3.**

**Recent to Older Underwriting Flow is covered in section B.2.3.**

**Underwriting Expected Casualty Rate is covered in section B.4.1.**

**Initial Dollars Underwritten per Stage is covered in section B.2.3.**

**B.3.3 Expected Casualty Rate of Older Underwriting (dollars/Year)**

=  $\int$  (Recent to Older Expected Casualty Rate Flow-Older to Oldest Expected Casualty Rate Flow) dt + [Underwriting Expected Casualty Rate\*Initial Dollars Underwritten per Stage]

Description: A measure of the total claims generated by the older pool of underwriting per year

**Recent to Older Expected Casualty Rate Flow is covered in section B.3.2.**

**Older to Oldest Expected Casualty Rate Flow (dollars/(Year\*Year))**

= Average Expected Casualty Rate of Older Underwriting\*Older to Oldest Underwriting Flow

Description: An aging flow of claim generating policies

**Average Expected Casualty Rate of Older Underwriting (dmnl/Year)**  
= Expected Casualty Rate of Older Underwriting/Older Dollars Underwritten  
Description: The fraction of all older underwriting that will generate a claim this year

**Older Dollars Underwritten is covered in section B.2.3.**

**Older to Oldest Underwriting Flow is covered in section B.2.3.**

**Underwriting Expected Casualty Rate is covered in section B.4.1.**

**Initial Dollars Underwritten per Stage is covered in section B.2.3.**

**B.3.4 Expected Casualty Rate of Oldest Underwriting (dollars/Year)**

=  $\int$  (Older to Oldest Expected Casualty Rate Flow-Expected Casualty Rate Expiration) dt + [Underwriting Expected Casualty Rate\*Initial Dollars Underwritten per Stage]

Description: A measure of the total claims generated by the oldest pool of underwriting per year

**Older to Oldest Expected Casualty Rate Flow is covered in section B.3.3.**

**Expected Casualty Rate Expiration (dollars/(Year\*Year))**

= Underwriting Outflow\*Average Expected Casualty Rate of Oldest Underwriting

Description: The outflow of claim generating policies

**Underwriting Outflow is covered in section B.2.3.**

**Average Expected Casualty Rate of Oldest Underwriting (dmnl/Year)**  
= Expected Casualty Rate of Oldest Underwriting/Oldest Dollars Underwritten  
Description: The fraction of all oldest underwriting that will generate a claim this year

**Oldest Dollars Underwritten is covered in section B.2.3.**

Underwriting Expected Casualty Rate is covered in section B.4.1.

Initial Dollars Underwritten per Stage is covered in section B.2.3.

## B.4 Scope

### B.4.1 Underwriting Expected Casualty Rate (dmnl/Year)

= Natural Casualty Rate\*(Current Scope of Insurance<sup>^</sup>Sensitivity of Expected Casualty Rate to Scope)

Description: When reserves are high the industry will attempt to capture market share from each other causing them to insure more risky clients overall as they branch out into areas of business that they have not previously insured

### Natural Casualty Rate (dmnl/Year)

0.0597

Description: The normal fraction of the underwritten policies that are insured

### Current Scope of Insurance (dmnl)

=  $\int$  (Change in Insurance Scope) dt + [Reference Scope]

Description: The current percentage of GDP insured

### Change in Insurance Scope (dmnl/Year)

= Indicated Change in Scope/Time to Change Insurance Scope

Description: The rate of change of the scope of insurance

### Indicated Change in Scope (dmnl)

= Indicated Scope-Current Scope of Insurance

Description: The change in the scope of insurance that is desired given the current capital and income situation.

- Indicated Scope (dmnl)

= Reference Scope\*Effect of Capital on Scope\*Effect of Income on Scope

Description: The fraction of total GDP that is insured is indicated through pressure from capital and profitability

- Effect of Capital on Scope (dmnl)

= Capital Adequacy<sup>^</sup>Sensitivity of Scope to Capital

- \* Capital Adequacy is covered in section B.8.1.

- \* Sensitivity of Scope to Capital (dmnl)

0.2

Description: strength of the power function for the relationship between capital adequacy and the scope of underwriting



- Effect of Income on Scope (dmnl)
  - = (Income Adequacy)<sup>0.2</sup> \* Sensitivity of Scope to Income
  - \* Sensitivity of Scope to Income (dmnl)
  - 0.2
  - \* Income Adequacy is covered in section B.9.2.

**Time to Change Insurance Scope (years)**

4.5

Description: The delay in adjusting the types of clients insured

Reference Scope (dmnl) 1

**Sensitivity of Expected Casualty Rate to Scope (dmnl)**

1

Description: The capital adequacy is raised to this power when determining the net effect on underwriting quality.

## B.5 Claims and Costs

### B.5.1 Claims Expense (dollars/Year)

= Total Claims Settled \* Fraction of Claims Paid

Description: The flow of claims being settled by the insurance industry and also being paid out to policy holders

### Total Claims Settled (dollars/Year)

= Pending Claim Pool / Average Delay for Claim Investigation

Description: The total value of all claims currently being settled whether they are paid or denied.

### Pending Claim Pool (dollars)

=  $\int (\text{Claims Incurred} - \text{Claims Denied} - \text{Claims Expense}) dt + [\text{Initial Claims}]$

Description: The stock of claims waiting to be settled

### Claims Incurred (dollars/Year)

= Normal Claims Incurred \* Claims Random Noise Output

Description: Total claims generated are computed in the underwriting quality view

- Normal Claims Incurred is covered in section B.3.1.
- Claims Random Noise Output is covered in section B.12.1.

**Claims Denied (dollars/Year)**

= Total Claims Settled\*(1-Fraction of Claims Paid)

Description: The total dollar value of claims that are denied for payment by the industry

**Initial Claims (dollars)**

= Normal Claims Incurred\*Average Delay for Claim Investigation

Description: The initial value of claims is set up in balanced equilibrium

- Normal Claims Incurred is covered in section B.3.1.

**Average Delay for Claim Investigation (years)**

2.678

Description: The length of time on average that it takes for a claim to be settled can be very short for certain kinds of insurance and very long for others

**Fraction of Claims Paid (dmnl)**

0.847

Description: This number was estimated by a linear regression of reported total claims on reported claims paid

**B.5.2 Non-Claims Costs per unit Exposure (dmnl/Year)**

= Other Operating Costs/Total Underwriting Exposure

Description: A calculation for ease of comparison with other variables

**Other Operating Costs (dollar/Year)**

= (Claims Handling Costs+Other Costs)+Commission Costs

Description: The total flow of non-claim expenses, used for financial reporting

**Claims Handling Costs (dollars/Year)**

= Total Claims Settled\*Claims Handling Costs per Dollar of Claims

Description: Costs arising from handling claims will tend to be proportional to the flow of claims being generated.

Total Claims Settled is covered in section B.5.1.

**Claims Handling Costs per Dollar of Claims (fraction)**

0.036

Description: The costs from adjusting and handling claims will vary directly with the size of the flow of claims for the industry

**Other Costs (dollars/Year)**

= Other Costs per Dollar of Underwriting Exposure\*Total Underwriting Exposure

Description: The flow of assorted other costs

**Other Costs per Dollar of Underwriting Exposure (dmnl/Year)**

0.015

Description: The assorted other costs of the industry are assumed to scale directly with the size of the book of business

**Total Underwriting Exposure is covered in section B.2.3.**

**Commission Costs (dollars/Year)**

= Deferred Commission Costs/Time to Pay Commissions

Description: The current flow of commissions costs

**Deferred Commission Costs (dollars)**

=  $\int$  (Commission Costs Accrued-Commission Costs) dt + [Initial Commissions]

Description: The stock of commission liabilities

- **Commission Costs Accrued (dollars/Year)**

= Premium Inflow\*Commission per Dollar of Premium Written

Description: The inflow of commissions

- **Initial Commissions (dollars)**

= Initial Premium\*Underwriting Inflow\*Commission per Dollar of Premium Written\*Time to Pay Commissions

Description: The initial value of the commissions to be paid

- Initial Premium is covered in section B.7.1.
- Underwriting Inflow is covered in section B.2.3.
- Commission per Dollar of Premium Written (years)

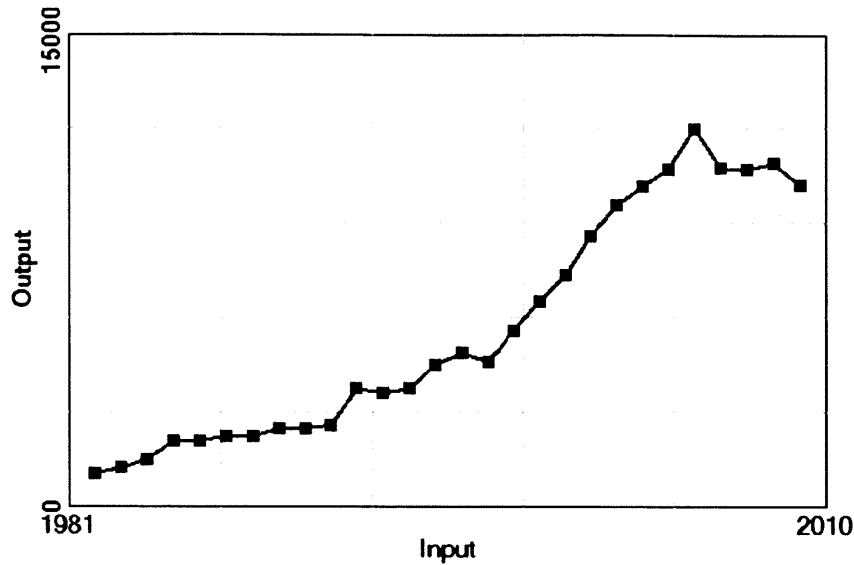
0.25

Description: Insurance companies pay agents a commission on policies written, the units of year represent the fact that the commission can be conceptualized as the years of premium flow the companies pay in order to secure the business

**Time to Pay Commissions (Year)**

0.56

Description: Commissions are paid to agents mostly over the course of the first year



**Figure B-2: Table for Historical Non-Life Claims**

**Total Underwriting Exposure is covered in section B.2.3.**

**B.5.3 Total Expenses per unit Exposure (dmnl/Year)**

= (Claims Expense+Other Operating Costs)/Total Underwriting Exposure

Description: The total expenses of the insurance industry per dollar of underwriting

**Claims Expense is covered in section B.5.1.**

**Other Operating Costs is covered in section B.5.2.**

**Total Underwriting Exposure is covered in section B.2.3.**

**B.5.4 Historical Non-Life Claims Incurred (dollars/Year)**

= Table for Historical Non-Life Claims(Time-1)\*1000000

Description: The total non-life claims incurred historically

**Table for Historical Non-Life Claims (dollars/Year)**

=[(1981,0)-(2010,150000)],(1982,10621.1),(1983,12509),(1984,15118.1),  
 (1985,20977),(1986,21018.6),(1987,22524.7),(1988,22582.5),(1989,24738.3),  
 (1990,24843.7),(1991,26055.6),(1992,37530.5),(1993,36183.2),(1994,37549.8),  
 (1995,45251),(1996,48866.4),(1997,46225.3),(1998,56046.4),(1999,65384),  
 (2000,73582.9),(2001,86308),(2002,95928.8),(2003,101898),(2004,107405),  
 (2005,120347),(2006,107624),(2007,107181),(2008,109145),(2009,102394)

Description: The flow of non life claims incurred by the industry

## B.6 Cost Forecasting

### B.6.1 Expected Future Costs (dmnl/Year)

= Expected Current Costs\*(1+Expected Percent Change in Costs\*Switch for Forecasting)

Description: The current projection of expected growth in costs given current perceived costs.

### Expected Current Costs (dmnl/Year)

= Perceived Costs\*(1+Expected Growth Rate for Costs\*Time to Perceive Changes in Costs)

Description: Since decision makers do not have access to the actual current costs, they must project their perception of current costs into the future by over the forecast horizon indicated by the time to perceive changes in costs.

### Perceived Costs (dmnl/Year)

=  $\int$  (Change in Cost Perception) dt + [Total Expenses per unit Exposure]

Description: This is the industry's perception of the total demand for seat miles

### Change in Cost Perception (dmnl/Year/Year)

= Gap in Cost Perception/Time to Perceive Changes in Costs  
Total Expenses per unit Exposure

- Gap in Cost Perception (dmnl/Year)

= Total Expenses per unit Exposure-Perceived Costs

– Total Expenses per unit Exposure is covered in section B.5.3.

### Expected Growth Rate for Costs (dmnl/Year)

=  $\int$  (Change in Expected Growth Rate) dt + [Initial Expected Growth Rate in Costs]

### Change in Expected Growth Rate (dmnl/Year/Year)

= (Indicated Growth Rate-Expected Growth Rate for Costs)/Time to Perceive Trend in Costs

- Indicated Growth Rate (dmnl/Year)

= (Perceived Costs-Reference Costs)/(Reference Costs\*Time Horizon for Reference Costs)

– Reference Costs (dmnl/Year)

=  $\int$  (Change in Reference Costs) dt + [Perceived Costs/(1+Initial Expected Growth Rate in Costs\*Time Horizon for Reference Costs)]

$$\begin{aligned} & * \text{ Change in Reference Costs (dmnl/Year/Year)} \\ & = (\text{Perceived Costs-Reference Costs})/\text{Time Horizon for Reference Costs} \end{aligned}$$

$$- \text{ Time Horizon for Reference Costs (Year)}$$

3.2

- Time to Perceive Trend in Costs (Year)
- 0.9

$$\text{Initial Expected Growth Rate in Costs (dmnl/Year)}$$

0

$$\text{Time to Perceive Changes in Costs (Year)}$$

0.35

Description: This is how long it takes the industry to perceive changes in costs

$$\text{Expected Percent Change in Costs (dmnl)}$$

$$= \text{Expected Growth Rate for Costs} * \text{Average Underwriting Term}$$

Description: The total growth of costs during the average underwriting term

$$\text{Switch for Forecasting (dmnl)}$$

1

## B.7 Premiums

### B.7.1 Current Premium per unit Exposure (dmnl/Year)

$$= \int (\text{Change in Premium}) dt + [\text{Initial Premium}]$$

Description: The actual premium per year per dollar of underwriting written. Units are dollars/year per dollar.

$$\text{Change in Premium (dmnl/Year/Year)}$$

$$= \text{Gap Between Target and Actual Premiums}/\text{Time to Change Premiums}$$

Description: Premium reductions will occur more quickly when indicated than will premium increases.

$$\text{Gap Between Target and Actual Premiums (dmnl/Year)}$$

$$= \text{Indicated Premium-Current Premium per unit Exposure}$$

Description: A measurement of the distance between current premiums and the target premiums

### **Indicated Premium (dmnl/Year)**

= MAX(Minimum Premium, Target Premium per Dollar of Underwriting)

Description: Insurers will not charge a premium higher than the actual replacement cost of the object insured

- **Minimum Premium (dmnl/Year)**

= Non-Claims Costs per unit Exposure

Description: This formulation assumes that insurers will not price below the marginal cost of servicing a policy, excluding claims.

- **Target Premium per Dollar of Underwriting (fraction/Year)**

= (Current Premium per unit Exposure)\*Effect of Profit on Premiums\*Effect of Capital on Premiums\*Effect of Costs on Premium

Description: The average premium indicated is adjusted from the current level by several effects.

- **Effect of Capital on Premiums (dmnl)**

= (Capital Adequacy)<sup>^</sup>Sensitivity of Premiums to Capital

Description: The multiplicative effect of capital on premiums

- \* **Sensitivity of Premiums to Capital (dmnl)**

-0.0875

Description: The aggressiveness of the power function for the effect of capital on premiums

- \* Capital Adequacy is covered in section B.8.1.

- **Effect of Costs on Premium (dmnl)**

= Expected Future Costs/Perceived Costs

- \* Expected Future Costs is covered in section B.6.1.

- \* Perceived Costs is covered in section B.6.1.

- **Effect of Profit on Premiums (dmnl)**

= (Income Adequacy)<sup>^</sup>Sensitivity of Premiums to Net Income

Description: The multiplicative change in premiums indicated by the current financial situation

- \* **Sensitivity of Premiums to Net Income (dmnl)**

-1.03

Description: Controls the slop of the power function for the effect of capital and earnings on premiums

- \* Income Adequacy is covered in section B.9.2.

### **Time to Change Premiums (years)**

1.2

Description: The length of time it takes agents to understand and adjust to new underwriting standards.

### **Initial Premium (dmnl/Year)**

= Initial((Other Costs+Claims Expense+Claims Handling Costs+(Target Return on Assets-Investment Return)\*Total Capital)/(Total Underwriting Exposure\*(1-Commission per Dollar of Premium Written/Average Underwriting Term)))

Description: Initialized to be in dynamic equilibrium so that given total underwriting and initial costs premiums would ensure that the return on assets was exactly equal to the target return.

**Other Costs is covered in section B.5.2.**

**Claims Expense is covered in section B.5.1.**

**Claims Handling Costs is covered in section B.5.2.**

**Target Return on Assets is covered in section B.9.2.**

**Investment Return is covered in section B.8.2.**

**Total Capital is covered in section B.8.1.**

**Total Underwriting Exposure is covered in section B.2.3.**

**Commission per Dollar of Premium Written is covered in section B.5.2.**

**Average Underwriting Term is covered in section B.2.3.**

### **B.7.2 Historical Premiums (dollars/Year)**

= Table for Historical Premiums(Time-1)\*1000000

Description: Total non-life premiums collected

#### **Table for Historical Premiums (dollars/Year)**

=[(1981,0)-(2010,200000)],(1982,15008.3),(1983,15364.2),(1984,17132.1),  
(1985,23494.9),(1986,30946.7),(1987,34171.4),(1988,35042.1),(1989,35375.2),  
(1990,35113.1),(1991,36323.5),(1992,51401.5),(1993,51184),(1994,56684.3),  
(1995,71601.8),(1996,79878.9),(1997,82968.3),(1998,89622.5),(1999,94276.7),  
(2000,96525.1),(2001,99620.5),(2002,114778),(2003,131325),(2004,151297),  
(2005,164747),(2006,168448),(2007,169468),(2008,165686),(2009,162433)

Description: Total non-life premiums for the insurance industry



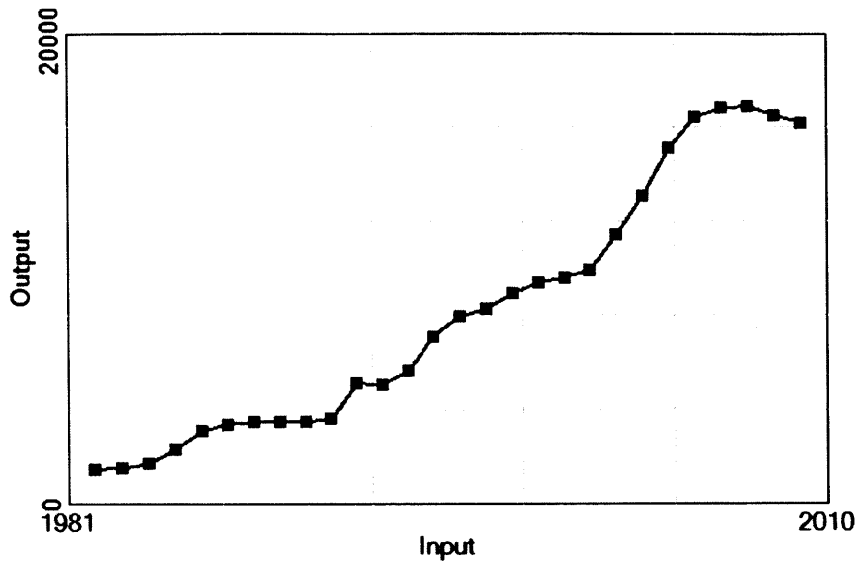


Figure B-3: Table for Historical Non-Life Claims

## B.8 Investment and Capital

### B.8.1 Capital Adequacy (dmnl)

=  $ZIDZ(\text{Total Capital}, \text{Desired Capital})$

Description: A measure of how much of the future expected liabilities of the industry can be covered by their current capital

#### Total Capital (dollars)

= Total Invested Capital

Description: The total reserves of the industry

#### Total Invested Capital (dollars)

=  $\int (\text{Investment Income} + \text{Insurance Cash Flows} - \text{Payments to Shareholders}) dt + [\text{Initial Invested Capital}]$

Description: The total capital of the insurance industry that is invested

#### Investment Income (dollars/Year)

=  $\text{MAX}(\text{Total Capital} * \text{Investment Return}, \text{Minimum Cash Flow})$

Description: Investments are assumed to generate returns on average at the given interest rate

- Investment Return is covered in section B.8.2.
- Minimum Cash Flow (dollars/Year)  
=  $-\text{Total Invested Capital} / \text{Time to Drain Capital}$

Description: The absolute minimum rate at which operating cash flow can drain reserves, maintains first order control over the capital stock

- Time to Drain Capital (years)  
= TIME STEP

Description: The time it takes to liquidate assets should the entire stock of invested capital need to be spent. Set to be the time step to preserve first order control. If all of the assets of the industry are drained there is no mechanism in the model for the industry to emerge from bankruptcy.

**Insurance Cash Flows (dollars/Year)**

= MAX(Total Premiums-Total Costs,Minimum Cash Flow)

Description: The cash flows to the insurance industry from collecting premiums minus the cash flows from administrative and adjustment expenses

- Total Premiums is covered in section B.2.2.
- Total Costs

= Total Expenses per unit Exposure\*Total Underwriting Exposure

Description: The total costs of the insurance industry

- Total Expenses per unit Exposure is covered in section B.5.3.
- Total Underwriting Exposure is covered in section B.2.3.

**Payments to Shareholders (dollars/Year)**

= Dividends Declared

Description: Payments to shareholders must be positive

- Dividends Declared is covered in section B.10.1.

**Initial Invested Capital (dollars) = Desired Capital**

**Desired Capital (dollars)**

= Critical Claims Solvency Ratio\*Claims Incurred

Description: The level of desired capital

**Critical Claims Solvency Ratio (years)**

1

Description: The desired capital of the industry is determined through a desire to have surplus capital over and above the reserve for claims

**Claims Incurred is covered in section B.5.1.**

## **B.8.2 Investment Return (dmnl/Year)**

= Interest Rate\*Switch for Impulse Response+Rate of Return\*(1-Switch for Impulse Response)

Description: Controls whether the simulation is conducting an interest rate test or using a more complex path for investment income

### **Interest Rate (dmnl/Year)**

= Test Pattern for Interest Rates

Description: The rate of return on insurance industry investments if they need to be held constant for testing.

### **Test Pattern for Interest Rates (dmnl/Year)**

= 0.02

**Switch for Impulse Response is covered in section B.1.2.**

### **Rate of Return (dmnl/Year)**

= (Return Stochastic Output\*Switch for Stochastic Return+(1-Switch for Stochastic Return)\*Historical Rate of Return)/100

Description: The rate of return being experienced by the simulated industry

**Return Stochastic Output is covered in section B.13.1.**

### **Switch for Stochastic Return (dmnl)**

0

Description: This controls whether the simulated industry experiences stochastic returns or historical returns

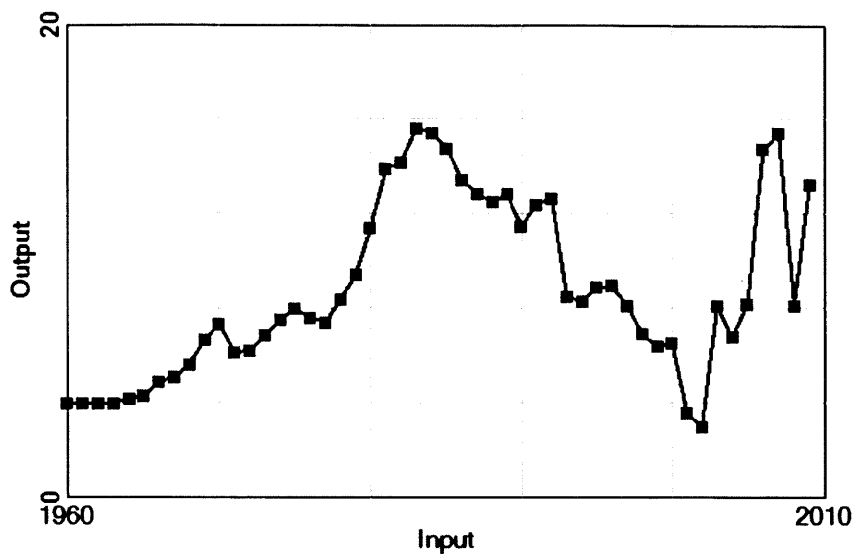
### **Historical Rate of Return (dmnl/Year)**

= Table for Insurance Rate of Investment Return(Time-1)

Description: The actual rate of return for the industry

### **Table for Insurance Rate of Investment Return (dmnl/Year)**

= [(1960,0)-(2010,20)],(1960,4),(1961,4),(1962,3.95),(1963,4),(1964,4.19),  
(1965,4.28),(1966,4.93),(1967,5.07),(1968,5.64),(1969,6.67),(1970,7.35),  
(1971,6.16),(1972,6.21),(1973,6.85),(1974,7.56),(1975,7.99),(1976,7.61),  
(1977,7.42),(1978,8.41),(1979,9.43),(1980,11.43),(1981,13.92),(1982,14.1882),  
(1983,15.6557),(1984,15.4378),(1985,14.7913),(1986,13.4245),(1987,12.8833),  
(1988,12.5062),(1989,12.8363),(1990,11.4925),(1991,12.4303),(1992,12.6901),  
(1993,8.51171),(1994,8.34505),(1995,8.89398),(1996,8.95692),(1997,8.15162),  
(1998,6.92274),(1999,6.4248),(2000,6.55457),(2001,3.56514),(2002,2.99837),  
(2003,8.12083),(2004,6.78911),(2005,8.21829),(2006,14.7384),(2007,15.4114),  
(2008,8.1393),(2009,13.2622)



**Figure B-4: Table for Historical Insurance Rate of Investment Return**

Description: The annual rate of return on investments by the insurance industry as observed historically and expressed in percentages. Data before 1981 is the yield on treasury securities.

## B.9 Profitability Measures

### B.9.1 Combined Ratio (dmnl)

= Loss Ratio+Expense Ratio

Description: The current ratio is the ratio of total expenses to total premiums.

#### Loss Ratio (dmnl)

= Claims Expense/Total Premiums

Description: The loss ratio measures the profitability of the underwriting business excluding administrative costs.

**Claims Expense is covered in section B.5.1.**

**Total Premiums is covered in section B.2.2.**

#### Expense Ratio (dmnl)

= Other Operating Costs/Total Premiums

Description: The expense ratio measures the fraction of premium income that is spent on general expenses other than the payment of claims.

**Other Operating Costs is covered in section B.5.2.**

**Total Premiums is covered in section B.2.2.**

### **B.9.2 Income Adequacy (dmnl)**

$$= \text{MAX}((1+\text{Return on Assets})/(1+\text{Target Return on Assets}),0)$$

**Return on Assets (dmnl/Year)**

$$= \text{ZIDZ}(\text{Perceived Net Income},\text{Total Capital})$$

**Perceived Net Income (dollars/Year)**

$$= \int (\text{Change in Net Income Perception}) dt + [\text{Net Income}]$$

Description: The currently perceived return on equity varies from the actual due to delays in measuring and reporting the return on equity as well as delays in accepting that changes in return on equity will last long enough to take action based on them

**Change in Net Income Perception (dollars/Year/Year)**

$$= \text{Gap in Net Income Perception}/\text{Time to Adjust Net Income Perception}$$

Description: The rate of change in return on equity perceptions

- **Gap in Net Income Perception (dollars/Year)**

$$= \text{Net Income}-\text{Perceived Net Income}$$

Description: The difference between the perceived level of return on equity and the actual level

- **Time to Adjust Net Income Perception (years)**

$$2$$

Description: Time passes before perceptions about net income are solidified.

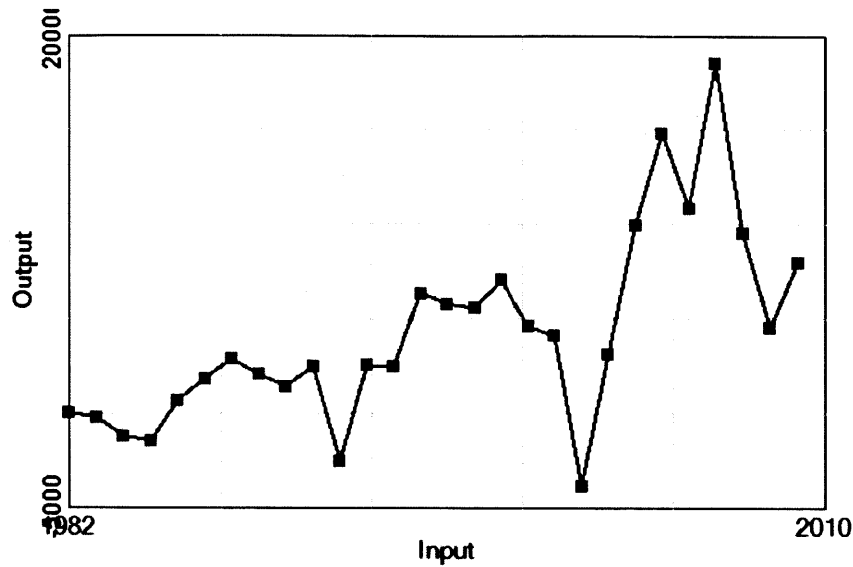
**Net Income is covered in section B.11.1.**

**Total Capital is covered in section B.8.1.**

**Target Return on Assets (dmnl/Year)**

$$0$$

Description: The target return on equity for the industry



**Figure B-5: Table for Historical Insurance Rate of Investment Return**

### B.9.3 Reported Net Income (dollars/Year)

= Report Variable(Net Income,Reporting Period)

Description: The net income of the industry as reported over the indicated reporting period. This formulation uses the macro for data reporting described in appendix A and chapter 2.

#### Reporting Period (Year)

1

Description: The length of time between reported periods

#### Historical Income (dollars/Year)

= Table for Historical Operating Income(Time-1)\*1000000

Description: The reported operating income of the industry

#### Table for Historical Operating Income

=[(1982,-5000)-(2010,20000)],(1982,18.561),(1983,-162.779),(1984,-1186.08),  
 (1985,-1419.76),(1986,692.928),(1987,1900.8),(1988,2907.26),(1989,2086.24),  
 (1990,1486.02),(1991,2511.9),(1992,-2518.27),(1993,2573.28),(1994,2497.26),  
 (1995,6427.15),(1996,5824.66),(1997,5617.14),(1998,7098.19),(1999,4655.15),  
 (2000,4126.88),(2001,-3812.23),(2002,3167.88),(2003,10019.5),(2004,14887.9),  
 (2005,10928.4),(2006,18586),(2007,9586.66),(2008,4567.13),(2009,8007.02)

## **B.10 Dividends**

### **B.10.1 Dividends Declared (dollars/Year)**

= MAX(Indicated Dividend,0)

Description: The dividend paid by the industry must be greater than zero.

### **Indicated Dividend (dollars/Year)**

= Perceived Net Income\*Dividend Payout Ratio

Description: The dividend indicated by the payout ratio and the net income.

**Perceived Net Income is covered in section B.9.2.**

### **Dividend Payout Ratio (dmnl)**

0.11

Description: For dynamic equilibrium either set the target return on assets to zero or set this to 1.

## **B.11 Financial Statements**

### **B.11.1 Earnings Retained (dollars/Year)**

= Net Income-Dividends Declared

Description: The total earnings retained (annualized)

### **Net Income (dollars/Year)**

= Total Revenue-Claims Expense-Other Operating Costs

Description: The instantaneous flow of net income into the industry

### **Total Revenue (dollars/Year)**

= Investment Income+Total Premiums

Description: The total flow of revenue into the industry

**Investment Income is covered in section B.8.1.**

**Total Premiums is covered in section B.2.2.**

**Claims Expense is covered in section B.5.1.**

**Other Operating Costs is covered in section B.5.2.**

**Dividends Declared is covered in section B.10.1.**

### **B.11.2 Shareholder's Equity (dollars)**

= Total Assets-Total Liabilities

**Total Assets (dollars)**

= Total Capital

**Total Capital is covered in section B.8.1.**

**Total Liabilities (dollars)**

= Deferred Commission Costs

**Deferred Commission Costs is covered in section B.5.2.**

## **B.12 Random Noise Generation**

### **B.12.1 Claims Random Noise Output (dmnl)**

= Claims Noise Mean+Claims Pink Noise\*Switch for Claims Random Noise

Description: The final output of the claims random noise generation process

**Claims Noise Mean (dmnl)**

1

Description: Ensures that the noise value will cause the variable it is modifying to be unchanged on average

**Claims Pink Noise (dmnl)**

=  $\int (\text{Claims Change in Pink Noise}) dt + [0]$

Description: A dimensionless quantity that modifies another with a stream of correlated noise

**Claims Change in Pink Noise (dmnl/Year)**

= Claims Gap Between Pink and White Noise/Claims Noise Correlation Time

Description: The change in the pink noise value occurs with an average delay of the noise correlation time



### **Claims Gap Between Pink and White Noise (dmnl)**

= Claims Scaled White Noise-Claims Pink Noise

Description: The gap that the pink noise process is trying to close

- **Claims Scaled White Noise (dmnl)**

= Claims Noise Standard Deviation\*SQRT(24\*Claims Noise Correlation Time/TIME STEP )\*Claims White Noise

Description: The white noise should be scaled so that it exhibits the proper characteristics

- **Claims Noise Standard Deviation (dmnl)**

0.05

Description: The standard deviation of the random noise

- **TIME STEP (Year)**

0.015625

Description: The time step for the simulation.

- **Claims White Noise (dmnl)**

= Random UNIFORM(-0.5, 0.5, Claims Noise Seed )

- \* **Claims Noise Seed (dmnl)**

1

Description: The seed value allows for repeatable tests using the same random inputs

### **Claims Noise Correlation Time (years)**

1

Description: A measure of the inverse of the largest frequency the noise exhibits

### **Switch for Claims Random Noise (dmnl)**

0

Description: Allows the user to switch the claims noise on or off (value set to 1 or 0 respectively)

## **B.12.2 GDP Random Noise Output (dmnl)**

= GDP Noise Mean+GDP Pink Noise\*Switch for GDP Random Noise

Description: Final noise output for GDP

### **GDP Noise Mean (dmnl)**

1

Description: Ensures that the noise value will cause the variable it is modifying to be unchanged on average

### **GDP Pink Noise (dmnl)**

$$= \int (\text{Change in GDP Pink Noise}) dt + [0]$$

Description: A dimensionless quantity that modifies another with a stream of correlated noise

### **Change in GDP Pink Noise (dmnl/Year)**

$$= \text{GDP Gap Between Pink and White Noise} / \text{GDP Noise Correlation Time}$$

Description: The change in the pink noise value occurs with an average delay of the noise correlation time

### **GDP Gap Between Pink and White Noise (dmnl)**

$$= \text{GDP Scaled White Noise} - \text{GDP Pink Noise}$$

Description: The gap that the pink noise process is trying to close

- **GDP Scaled White Noise (dmnl)**

$$= \text{GDP Noise Standard Deviation} * \text{SQRT}(24 * \text{GDP Noise Correlation Time} / \text{Time STEP}) * \text{GDP White Noise}$$

Description: The white noise should be scaled so that it exhibits the proper characteristics

- **GDP Noise Standard Deviation (dmnl)**

0.04

Description: The standard deviation of the random noise, estimated from an autocorrelation spectrum of the historical data

- **GDP White Noise (dmnl)**

$$= \text{Random UNIFORM}(-0.5, 0.5, \text{GDP Noise Seed})$$

- \* **GDP Noise Seed (dmnl)**

1

Description: The seed value allows for repeatable tests using the same random inputs

### **GDP Noise Correlation Time (years)**

9

Description: A measure of the inverse of the largest frequency the noise exhibits, estimated from an autocorrelation spectrum of the historical data

### **Switch for GDP Random Noise (dmnl)**

0

Description: Allows the user to switch the pink noise on or off by setting the value to 1 or 0 respectively.

## B.13 Stochastic Return

### B.13.1 Return Stochastic Output (dmnl/Year)

= Stochastic Return\*Switch for Return Random Noise

Description: Final noise output for Return

#### Stochastic Return (dmnl/Year)

=  $\int$  (Change in Stochastic Return) dt + [Return Noise Long Run Mean]

Description: A dimensionless quantity that modifies another variable with correlated noise

#### Change in Stochastic Return (dmnl/Year/Year)

= Gap Between Mean and Current Level/Return Mean Reversion Delay+Scaled Change in Gaussian Noise

Description: The change in the pink noise value occurs with the average delay indicated.

#### Gap Between Mean and Current Level (dmnl/Year)

= Return Noise Long Run Mean-Stochastic Return Description: The gap that the pink noise process is trying to close

#### Return Mean Reversion Delay (years)

2

Description: A measure of the inverse of the largest frequency the noise exhibits, estimated from a parametrization of a financial model

#### Scaled Change in Gaussian Noise (dmnl/Year/Year)

= Return Noise Standard Deviation\*Change in Return Gaussian Noise

Description: The noise should be scaled so that it exhibits the proper characteristics

- Return Noise Standard Deviation (dmnl)

= Variance State\*High Standard Deviation for Return+(1-Variance State)\*Low Standard Deviation for Return

Description: The standard deviation of the random noise

- Variance State is covered in section B.13.2.

- High Standard Deviation for Return (dmnl)

6.9

Description: The estimated standard deviation of the normal random variable when the variance is high.

– Low Standard Deviation for Return (dmnl)

2.8

Description: The estimated standard deviation of the normal random variable when the variance is low.

• Change in Return Gaussian Noise (dmnl/Year/Year)

= RANDOM NORMAL(-100, 100 , 0 , 1 , Return Noise Seed )/SQRT(TIME STEP/Wiener Unit Fix)/(Wiener Unit Fix)^2

Description: A discretization of a continuous Wiener process. The unit fix variables are set to 1, and allow the output to have the correct units, given that the SQRT function will only accept dimensionless inputs.

– Return Noise Seed (dmnl)

3

Description: The seed value allows for repeatable tests using the same random inputs

– Wiener Unit Fix (Year)

1

**Return Noise Long Run Mean (dmnl/Year)**

10.5

Description: As the "goal" of the negative feedback loop, the long run mean of the stochastic process will serve as the anchor of the mean reversion

**Switch for Return Random Noise (dmnl)**

0

Description: Allows the user to switch the pink noise in returns on or off

**B.13.2 Variance State (dmnl)**

=  $\int$  (Increment Variance State-Drain Variance State) dt + [0]

Description: Implements a Markov process for the current variance state of the random variable

**Increment Variance State (dmnl/Year)**

= (1-Variance State)\*IF THEN ELSE( Random Variable for Markov > Transition to High, 1 , 0 )/TIME STEP

Description: The transition from a state of low variance to a state of high variance should only occur if the current state is equal to zero. The time step scalar ensures that the flow will be sufficient to make the state receive a full unit over one model time step.

**Random Variable for Markov (dmnl)**

= Random UNIFORM(0, 1, Return Noise Seed )

Description: A uniform random variable valued between zero and one

**Transition to High (dmnl)**

0.77

Description: The percentage chance that the variance state will transition from low to high

**Drain Variance State (dmnl/Year)**

= Variance State\*IF THEN ELSE( Random Variable for Markov >Transition to Low , 1 , 0 )/TIME STEP

Description: The transition from a state of high variance to a state of low variance should only occur if the current state is equal to one. The time step scalar ensures that the flow will be sufficient to make the state lose a full unit over one model time step.

**Transition to Low (dmnl)**

0.17

Description: The percentage chance that the state of the Markov process will transition from high to low

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# Appendix C

## Implementing a Hand Calculation of Skewness in a System Dynamics Model

### C.1 Skewness

Skewness, or the third standardized moment of a random variable, is a useful calculation for analyzing data that is known to depart from a normal distribution. However, the usual calculation of skew is inconvenient for implementation in the time domain because it requires a memory of the difference between all of the past observations  $X$  and the current sample mean  $\mu$ , which changes with each observation:

$$skewness = E \left[ \left( \frac{X - \mu}{\sigma} \right)^3 \right] \quad (C.1)$$

By expanding the discrete time version of that definition I implement a calculation of current sample skewness using the previously observed data only. The following equations document this transformation:

$$skewness = \frac{1}{N} \sum_1^N \left[ \left( \frac{X - \mu}{\sigma} \right)^3 \right] \quad (C.2)$$

$$= \frac{1}{N \cdot \sigma^3} \sum_1^N [(X - \mu)^3] \quad (C.3)$$

$$= \frac{1}{N \cdot \sigma^3} \sum_1^N (X^3 - 3\mu \cdot X^2 + 3\mu^2 \cdot X - \mu^3) \quad (C.4)$$

$$= \frac{1}{\sigma^3} (E[X^3] - 3\mu \cdot E[X^2] + 2\mu^3) \quad (C.5)$$

Where  $N$  is the number of samples drawn so far,  $X$  is the observed value of the variable,  $\mu$  is the current sample mean,  $E$  is the expectation operator, and  $\sigma$

is the current sample standard deviation. The calculations that remain are easy to accomplish with minor additions to the summary statistics model published in *Business Dynamics* (Sterman 2000).