Sensitivity and Simulation Analysis in Excel Without Programming

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Most finance textbooks talk about the benefits of conducting sensitivity and/or Monte Carlo simulation analyses in financial modeling, but mostly limit coverage to commenting on these techniques in passing. This is particularly true when it comes to simulation analysis, which typically requires the use of a third-party add-in or a significant level of programming expertise in VBA. We provide an extensive, step-by-step guide demonstrating how data tables in Excel can be used to easily implement sensitivity and simulation analyses. This approach requires only minor modifications to the base-case model without the need for any programming experience.

INTRODUCTION

"Everybody talks about the weather, but nobody does anything about it"
- Charles Dudley Warner

Shortly after introducing the topic of capital budgeting, most undergraduate corporate finance textbooks briefly address the importance of conducting robustness checks on these models, including sensitivity analysis, scenario analysis, and Monte-Carlo simulation. However, as with the weather in the quote above, they almost universally limit their coverage to merely commenting on these techniques in passing. This is particularly true when it comes to simulation analysis, which typically requires either the use of a third-party add-in (such as Crystal Ball or @Risk), or a significant level of programming expertise in VBA (Visual Basic for Applications) to handle the iteration process. This paper demonstrates how data tables in Excel can be used to easily implement sensitivity and simulation analyses with only minor modifications to a base case model and without the need for any programming experience. As a result, instructors can give students a more thorough understanding of these analytical techniques through hands-on exercises without the need for costly third-party software or time-consuming instruction in VBA.

COVERAGE OF WHAT-IF ANALYSES IN TEXTBOOKS AND PREVIOUS ARTICLES

We examined nine commonly used introductory/intermediate financial management texts (Adair, 2004; Benninga and Mofkadi, 2018; Berk, Demarzo, and Harford, 2015; Brigham and Erhardt, 2016; Holden, 2014; Mayes and Shank, 2007; Moyer, Mcguigan, and Rao, 2017; Ross, Westerfield, and Jaffe, 2013; Ross, Westerfield, and Jordan, 2019; Ross, Westerfield, and Jordan, 2020). All of these follow the introduction of the topic of capital budgeting with discussions of the importance of sensitivity and scenario analyses. The use of data tables as a sensitivity/scenario analysis tool is discussed and implemented in five of the texts (Berk, Demarzo and Harford, 2015; Benninga and Mofkadi, 2018; Mayes and Shank, 2007; Holden, 2014; Adair, 2004). However, the topic of simulation analysis is often given relatively short shrift: it is mentioned and discussed (albeit briefly) in three of the texts (Ross, Westerfield, and Jaffe, 2013; Brigham and Erhardt, 2016; Mayes and Shank, 2007). However, only one text (Mayes and Shank, 2007) goes into the technical aspects of implementing an actual simulation (using an add-in provided with the text).
Other studies address implementation of simulations in Excel. Craft (2003) demonstrates how to simulate data in Excel for teaching econometrics. Rozycki (2011) lays out the general process of converting a static, deterministic capital budgeting spreadsheet to one useful for conducting Monte-Carlo simulations. However, while both cover the

use of data tables in simulations, they leave out many, if not most, of the fine details necessary for making these simulations implementable by introductory or intermediate Excel users.

DATA TABLES AND SENSITIVITY ANALYSIS

Data Tables are an excellent tool for conducting sensitivity analysis. The user can specify a list of values that Excel will use to replace an assumption, recalculate the model, and then report the results. As two possible examples, you could create a list of discount rates or growth rates in sales and have Excel calculate the Net Present Value (NPV) of a capital budgeting project which can then be used to generate the data needed to plot an NPV profile. Alternately, you could examine a set of possible portfolio weights of a two-security portfolio to find the potential expected values and standard deviations of the portfolios' returns. However, you can only specify the values for either one or two input assumptions at a time, so data tables can't be easily used to conduct a full-fledged scenario analysis where more than two variables might change.

This study provides an extended example of a basic capital budgeting analysis to illustrate how a data table can be created and how its results can be used to evaluate the project. The problem description is in a format suitable for distribution to students and is included in the Appendix. Additionally, the spreadsheet file used to generate all figures is available from the authors upon request.

Figure 1 presents a deterministic capital budgeting analysis including both the input assumptions and the pro forma statements where the model's calculations take place. Since the price will be decided by the firm, it is treated as a point estimate. Other than price, most of the input factors are assumed to be known with certainty; however, several factors, including the sales volume (in units), growth rate in the selling price per unit, the variable cost per unit, as well as its growth rate, are uncertain. While the uncertainty (either in the form of a standard deviation or a range of possible values surrounding the expected values) has been quantified, the deterministic model uses the expected values for the base case. These uncertainty measures are then used later in the sensitivity and simulation analysis.

Figure 1: Deterministic capital budgeting model

	A	B	C	D	E	F	G	H	I
1	Capital Budgeting Model								
2									
3		Inputs							
4		Unit Sales		120,000					
5		Initial Unit Price		$ 40.00					
6		Annual Growth in Price		3.00%					
7		Initial Unit Cost		$ 26.00					
8		Annual Growth in Cost		4.00%					
9		Fixed costs		$ 500,000.00					
10		Taxes		30%					
11									
12		Initial Investment		$ 4,500,000.00					
13		Depreciable Life		10					
14		Estimated Salvage Price		$ 2,000,000.00					
15									
16		Required return		10%					
17									
18		Model	0	1	2	3	4	5	6
19		Sales		$ 4,800,000.00	$ 4,944,000.00	$ 5,092,320.00	$ 5,245,089.60	$ 5,402,442.29	$ 5,564,515.56
20		COGS		$ 3,120,000.00	$ 3,244,800.00	$ 3,374,592.00	$ 3,509,575.68	$ 3,649,958.71	$ 3,795,957.06
21		Gross Profit		$ 1,680,000.00	$ 1,699,200.00	$ 1,717,728.00	$ 1,735,513.92	$ 1,752,483.58	$ 1,768,558.50
22		Fixed Costs		$ 500,000.00	$ 500,000.00	$ 500,000.00	$ 500,000.00	$ 500,000.00	$ 500,000.00
23		Depreciation		$ 450,000.00	$ 450,000.00	$ 450,000.00	$ 450,000.00	$ 450,000.00	$ 450,000.00
24		Taxable Income		$ 730,000.00	$ 749,200.00	$ 767,728.00	$ 785,513.92	$ 802,483.58	$ 818,558.50
25		Taxes		$ 219,000.00	$ 224,760.00	$ 230,318.40	$ 235,654.18	$ 240,745.07	$ 245,567.55
26		Net Income		$ 511,000.00	$ 524,440.00	$ 537,409.60	$ 549,859.74	$ 561,738.51	$ 572,990.95
27		Depreciation		$ 450,000.00	$ 450,000.00	$ 450,000.00	$ 450,000.00	$ 450,000.00	$ 450,000.00
28		Capital Expenditures	$ (4,500,000.00)	$ -	$ -	$ -	$ -	$ -	$ 1,940,000.00
29		Project Cash Flow	$ (4,500,000.00)	$ 961,000.00	$ 974,440.00	$ 987,409.60	$ 999,859.74	$ 1,011,738.51	$ 2,962,990.95
30									
31		NPV	$ 904,472.94						
32		IRR	13.41%						

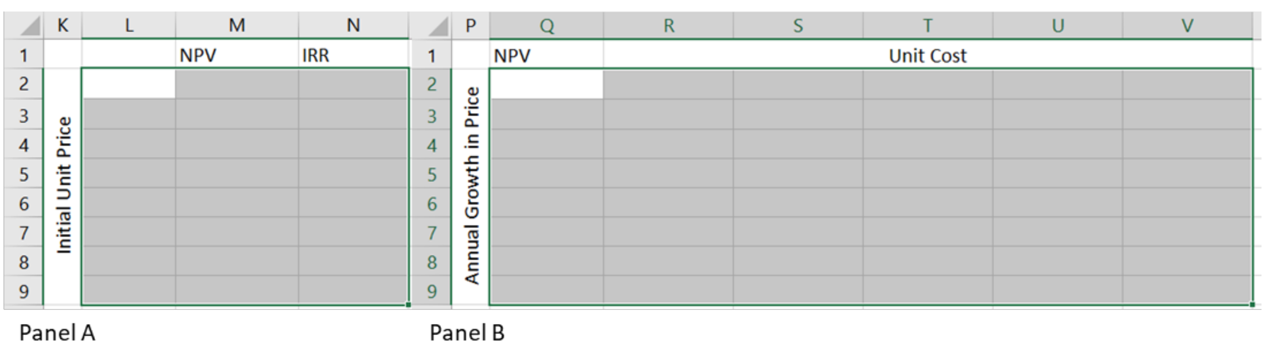
This type of analysis is similar to what a student might conduct to answer a homework problem or as part of a case analysis, such as Question 1 in the example included in the Appendix. A student should note that the NPV of $904,472.94 is positive and decide that this project should be accepted since it is expected to increase the value of the firm by that same amount.

However, the validity of that decision is only as good as the accuracy of the assumptions used to drive the model. An analyst may be concerned with estimation error in the assumptions. For example, holding all else constant, if the firm could sell each unit at a price higher than $40, the project's NPV should increase. However, the magnitude of the increase would be a function of multiple other assumptions and it could be quite complicated to build a single formula that could calculate it. Most students will instead simply use a slightly different input value and rerun the model to see how much the output value changes. Often, beginner students will do this manually, by typing in a new value into one of the assumption cells and then using Copy / Paste Special as Value to record the result. Excel's data tables allow you to automate this repetition.

Constructing a Data Table

There are five steps to constructing a data table once the deterministic model is complete. A data table has three parts: the input values, the output formula(s), and the results. Figure 2 depicts the initial set up for a data table that explores changes in one or more output values resulting from changes in a single input assumption (i.e., a "one-way" data table) in Panel A and a "two-way" data table (one that allows changes in two input assumptions), in Panel B. Technically, the labels are not part of the data tables but are included to help users remember what is included In the table. The actual data table ranges are L2:N9 for the one-way table in Panel A and R2:V9 for the two-way table in Panel B. The data tables explore the resulting NPV's sensitivity to the initial unit price in the one-way data table and to joint changes in the initial unit cost and the annual percentage growth rate in price in the two-way data table.

Figure 2. Data Table Ranges



1. *Create a list of input values*

After selecting a location on the same worksheet as the cells where initial assumptions are located, type in the list of input values to be used in the data table.[1] If only one input variable will be changed (i.e., a one-way data table), the list can be arranged in either a row or a column. In Panel A of Figure 3, the list of unit prices is located in Column L. For a two-way data table, one set of input values will be located in the left-most column of the range and the other set in the top-most row. Panel B of Figure 3 illustrates this with the list of Annual Growth Rates in Unit Price in Column Q and the list of Unit Costs in Row 2.

Figure 3. Data Table Input Values

Panel A

	K	L	M	N
1			NPV	IRR
2	Initial Unit Price			
3		$ 36.00		
4		$ 38.00		
5		$ 40.00		
6		$ 42.00		
7		$ 44.00		
8		$ 46.00		
9		$ 48.00		

Panel B

	P	Q	R	S	T	U	V
1		NPV			Unit Cost		
2	Annual Growth in Price		$ 20.00	$ 23.00	$ 26.00	$ 29.00	$ 32.00
3		1.50%					
4		2.00%					
5		2.50%					
6		3.00%					
7		3.50%					
8		4.00%					
9		4.50%					

2. Set up formulas for the desired outputs

After setting up the list(s) of input values, the next step is to insert a link to the input factor, intermediate result, or output formula of interest from the model (note: we subsequently refer to this as the "link formula"). For example, NPV is calculated in Cell C31 in Figure 1, and IRR is calculated in Cell C32. A one-way data table allows us to examine the response of both measures to variations in a single input (in this case, the initial unit price) in the same table. In a one-way data table, the link formula or formulas for the desired output value or values are placed in the top-most row of the data table (Row 2 in Panel A of Figure 4). For a two-way data table, the link formula is placed in the upper left cell of the data table (Cell Q2 in Panel B of Figure 4). Note that only one output measure can be examined at a time with a two-way data table.

Figure 4. Links to formulas to be reported in Data Table

Panel A

	K	L	M	N
1			NPV	IRR
2	Initial Unit Price		$ 904,472.94	13.41%
3		$ 36.00		
4		$ 38.00		
5		$ 40.00		
6		$ 42.00		
7		$ 44.00		
8		$ 46.00		
9		$ 48.00		

=C31 (M2)
=C32 (N2)

Panel B

	P	Q	R	S	T	U	V
1		NPV			Unit Cost		
2	Annual Growth in Price	$ 904,472.94	$ 20.00	$ 23.00	$ 26.00	$ 29.00	$ 32.00
3		1.50%					
4		2.00%					
5		2.50%					
6		3.00%					
7		3.50%					
8		4.00%					
9		4.50%					

=C31 (Q2)

3. Highlight the table range

Once the input values and link formulas have been placed in the appropriate cell or cells, highlight the entire table, including the input values and link formulas (but not any labels) as shown in Figure 5.

Figure 5. Highlight range for Data Table

	K	L	M	N
1			NPV	IRR
2	Initial Unit Price		$ 904,472.94	13.41%
3		$ 36.00		
4		$ 38.00		
5		$ 40.00		
6		$ 42.00		
7		$ 44.00		
8		$ 46.00		
9		$ 48.00		

Panel A

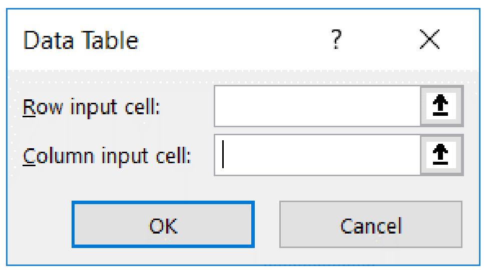
	P	Q	R	S	T	U	V
1		NPV			Unit Cost		
2	Annual Growth in Price	$ 904,472.94	$ 20.00	$ 23.00	$ 26.00	$ 29.00	$ 32.00
3		1.50%					
4		2.00%					
5		2.50%					
6		3.00%					
7		3.50%					
8		4.00%					
9		4.50%					

Panel B

4. *Open the Data Table dialog box using the Excel menu*

To open the data table dialog box, select the Data ribbon, then What-If Analysis and then Data Table. This brings up the dialog box shown in Figure 6.

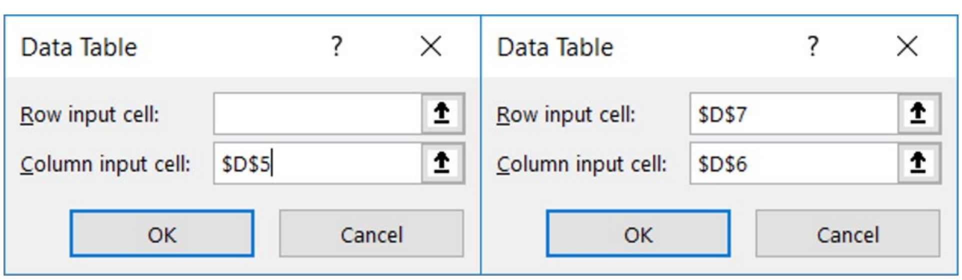
Figure 6. Data Table Dialog Box



5. *Specify the input cells in the dialog box*

A one-way data table makes use of only one of these input cells. In contrast, a two-way data table uses one for each of the input lists. In the example, the list of selling prices is organized as a column, so the column input cell corresponds with these values. As was shown in Figure 1, the initial unit price is stored in cell D5. Therefore, enter D5 (or click on that particular cell) into the Column input cell box, as shown in Panel A of Figure 7. For the two-way data table, the unit price growth rates are located in the left-most column, while the unit costs are in the top-most row. Therefore, enter D6, the unit price growth rate cell, into the Column input cell, and D7, the initial unit cost cell, into the Row input cell. These are shown in Figure 7, Panel B.

Figure 7. Input cells for one-way and two-way Data Tables



Panel A Panel B

After clicking OK or pressing Enter, Excel takes each value in the left-most column in the one-way table (or each combination of values in the left-most column and top-most row for the two-way table), inputs it into the cell(s) specified in the dialog box (either D5 in the case of the one-way data table or both D7 and D6 in the case of the two-way data table), calculates all of the formulas in the model, gets results for the NPV in cell C31 (and also for the IRR in Cell C32 for the one-way table), and records each result in the data table in the same row (or intersection of row and column) as the input value(s) used to generate them. After formatting for ease of readability, the data tables should look like Figure 8.[2]

Figure 8. Sensitivity Analysis output using Data Tables

	K	L	M	N
1			NPV	IRR
2	Initial Unit Price		$ 904,472.94	13.41%
3		$ 36.00	$ (660,272.37)	7.13%
4		$ 38.00	$ 122,100.28	10.49%
5		$ 40.00	$ 904,472.94	13.41%
6		$ 42.00	$ 1,686,845.60	15.99%
7		$ 44.00	$ 2,469,218.26	18.32%
8		$ 46.00	$ 3,251,590.92	20.44%
9		$ 48.00	$ 4,033,963.57	22.38%

Panel A

	P	Q	R	S	T	U	V
1		NPV			Unit Cost		
2	Annual Growth in Price	$ 904,472.94	$ 20.00	$ 23.00	$ 26.00	$ 29.00	$ 32.00
3		1.50%	$ 2,788,466.83	$ 1,588,273.14	$ 388,079.46	$ (812,114.22)	$ (2,012,307.91)
4		2.00%	$ 2,958,455.43	$ 1,758,261.75	$ 558,068.06	$ (642,125.62)	$ (1,842,319.31)
5		2.50%	$ 3,130,578.93	$ 1,930,385.24	$ 730,191.56	$ (470,002.13)	$ (1,670,195.81)
6		3.00%	$ 3,304,860.31	$ 2,104,666.63	$ 904,472.94	$ (295,720.74)	$ (1,495,914.43)
7		3.50%	$ 3,481,322.75	$ 2,281,129.07	$ 1,080,935.38	$ (119,258.30)	$ (1,319,451.98)
8		4.00%	$ 3,659,989.60	$ 2,459,795.91	$ 1,259,602.23	$ 59,408.55	$ (1,140,785.14)
9		4.50%	$ 3,840,884.38	$ 2,640,690.69	$ 1,440,497.01	$ 240,303.33	$ (959,890.36)

Panel B

Analysis of Data Table Results

The output of the one-way data table in Panel A, indicates that, holding all else constant at the base values, the breakeven initial unit price is between $36 and $38. The results of the two-way data table in Panel B show that the NPV of this particular capital budgeting project is much more sensitive to changes in the initial unit cost than to changes in the unit price growth rate. For example, at the base case values of 3% annual price growth and $26 initial unit cost, the expected NPV is $904,472.94. A 0.5% increase (decrease), equivalent to one standard deviation, in the unit price growth rate will cause the NPV to increase (decrease) by $176,462.44 ($174,281.38). However, a $3 decrease (increase) in initial unit cost, also equivalent to a one standard deviation change, will cause the NPV to increase (decrease) by $1,200,193.68.[3] Using this, a student should be able to see that it is more important to get a good estimate for the initial unit cost than for the annual price growth rate. By constructing additional data tables for other factors with uncertainty, a student would have the results needed to answer Question 2 in the Appendix example.

SIMULATION ANALYSIS

While data tables can be useful when examining the effects of uncertainty, they are limited to analyses of one (or two) variables at a time, with the others being held constant. However, they fall short in situations where uncertainty occurs across more than two inputs simultaneously. Using analytic methods on models with anything more than a trivial number of inputs quickly becomes impractical. As an example, the capital budgeting project used as the example in the previous section would have ten independent variables that might have considerable interaction with each other. Simulation analysis provides a tool that can be used to address these issues.

Simulations are commonly used in any number of common finance settings in addition to capital budgeting. Portfolio managers commonly use simulations to calculate Value at Risk (VaR) for assessing portfolio risk. Financial planners employ use them to determine the likelihood of clients' financial ruin over various time intervals given various mixtures of asset classes. Financial engineers use simulations to determine the values of complicated options without easily tractable closed-form solutions. Finally, fixed-income specialists use them to assess the joint impact of the numerous options embedded in asset-backed securities.

General Procedure for Conducting a Simulation

The procedure for conducting a simulation in Excel "manually" (i.e. without resorting to VBA for iterating the process or as pseudocode before implementing in VBA) has the following steps:

1. Generate input values for each factor that is intended to vary

This is typically done with random number generators based on appropriate probability distributions and may be performed using VBA functions such as RND() or (in our examples) using worksheet functions such as RAND() or RANDBETWEEN(). For variables with probability distributions other than uniform, the result of the RAND() function can be used as an argument in another function. For example, to calculate a variable with a standard normal distribution, you could use =NORM.S.INV(RAND()), which takes a uniform variable between 0 and 1 and inverts this on the standard normal cumulative distribution function to find the associated z-score. It should be noted that the RAND() function updates every time a new value is typed into any cell or any time that Excel starts a new round of calculation, including when the user hits the F9 key for manual recalculation.

2. Enter inputs into the model to generate output results

This step should not require any changes to a model that a student may have constructed to find the results for the base case.

3. Copy output results to a new range and paste as Values

To save the results of a particular iteration, they must be stored in a different (and empty) location since the main output location will be reused for subsequent iterations. The results must be stored as values since formulas will be recalculated at each iteration so Copy / Paste Special as Value could be used.

4. Repeat Steps 1 through 3 for N iterations

The Law of Large Numbers tells us that the greater the number of iterations, the better the estimate of the output's probability distribution will be. Note that there is a trade-off between the quality of the estimate and the computing power required (i.e., the time needed to conduct all of the calculations).[4] For example, with 100 iterations, there may be substantial differences between the estimated mean and standard deviation calculated by different students even when using the same model and input distributions. However, with 1,000,000 iterations, the estimates of the output distribution parameters should be much closer to being identical across students.

5. Calculate summary statistics from the output results from all the iterations.

This final step typically involves calculation of common descriptive statistics for the distribution of output values, such as expected value, standard deviation, minimum, and maximum, but could also include other parameters specific to the type of situation being modelled. For example, with a capital budgeting analysis, the percentage of outcomes with a positive NPV might be particularly relevant. The number of outcomes with a value above or below a critical value can be calculated using a COUNTIF() function.

For students that have little or no programming experience, Step 3 and the iterative process described in Step 4 present the most difficulty. Each iteration's results must be stored in an empty row or column so that previous iterations' results are not overwritten. This requires either some way to track the number of iterations or to detect the first empty cell in a range. Both of these techniques are more in the realm of computer programming than finance. The VBA code in Figure 9 provides an example of copying the results in a particular range, moving to a different location, simulating a user holding the End key while pressing the down arrow to go to the last non-empty cell, moving one cell down to the first empty cell, and then pasting the results as Values. As long as the inputs are generated by formulas based on RAND() functions, the "Next i" statement causes the inputs to be recalculated and starts the next iteration. Most faculty would probably agree that it is more important to get students to understand the steps in the simulation procedure than to understand the specific syntax used in this code.

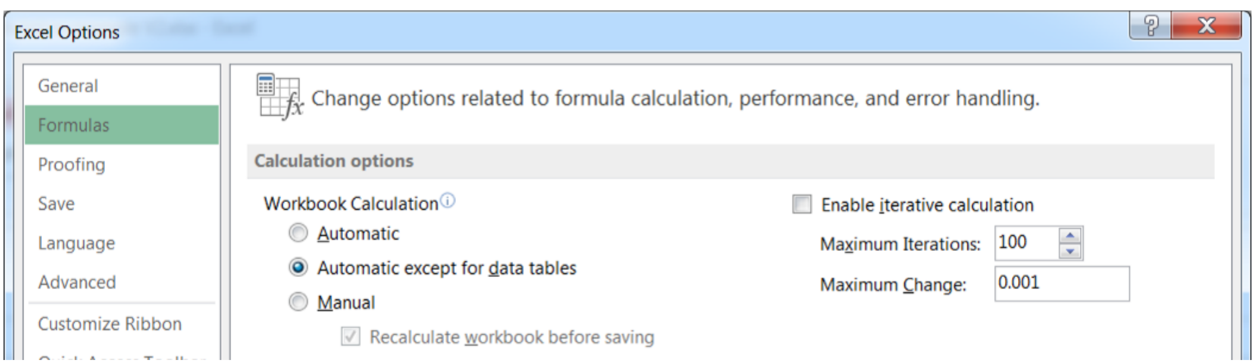
Figure 9. VBA code to conduct iterations

```
Sub Iterate()

Dim i As Integer
For i = 1 To 10000
   Range("C7:F7").Copy
   Range("C13").Select
   Selection.End(xlDown).Select
   ActiveCell.Offset(1, 0).Select
   Selection.PasteSpecial Paste:=xlPasteValues, Operation:=xlNone, SkipBlanks :=False,
Transpose:=False
Next i

End Sub
```

Recalculation of RAND() functions in Excel

Under the default settings, Excel automatically recalculates all formulas and functions, (including RAND() functions) any time the Enter key is pressed or the active cell is moved (such as by pressing an arrow key or clicking on a new cell with the mouse). This recalculation takes place when a new value is entered anywhere in the worksheet. Besides the Automatic setting, users can alternatively select from two other recalculation settings, Manual and Automatic Except Data Tables, as seen in Figure 10. If the worksheet includes either multiple data tables or large data tables, the user should select one of these other options, so that the large number of calculations that have to be repeated in a data table can be avoided, except when the data table is being created. If the user does need to have a data table recalculated, they have several options: they can press the F9 key to start manual recalculation, go through the same process as when the data table was initially created, or set the calculation option temporarily to Automatic.

Figure 10. Calculation options



Using Data Tables for Simulation Analysis

As shown earlier, a data table shows the results for the link formula(s) for each value in the list of input values. A user could generate a list of random values by writing a formula that could be copied down a row (or across a column). For example, instead of having the list of even incremented growth rates in Column Q and unit costs in Row 2 in Figure 8 Panel B, each of those values could be generated using a random number generator, as shown in Figure 11. However, as explained in Note 1, the formulas should be converted to values before running the data table. Generating multiple random values would handle the iteration (Step 4 above). The data table would insert each of these values into the input cell(s), run through all of the calculations in the model, and capture the model's output. Each result would be in a separate row (or column, depending on how the data table is organized), which would handle

Step 3, recording the results. In this way, you could conduct a basic simulation analysis. However, you would be limited to allowing only one or two variables to vary since data tables only permit values for either one or two input cells.

Figure 11. Randomized input values

	P	Q	R	S	T	U	V
1		NPV			Unit Cost		
2	Annual Growth in Price	$ 939,472.60	$ 26.06	$ 23.69	$ 25.26	$ 26.60	$ 25.63
3		3.28%					
4		3.51%					
5		2.77%					
6		2.38%					
7		2.86%					
8		2.82%					
9		2.78%					

=NORM.INV(RAND(),F7,G7)

=NORM.INV(RAND(),F7,G7)

A simulation with more than two random factors can be implemented by generating the input values outside the data table itself. Figure 12 below repeats the model from Figure 1 with one change: the original fixed values for the various input factors are replaced with formulas that incorporate the RAND() function.

Figure 12. Inputs allowing random fluctuations

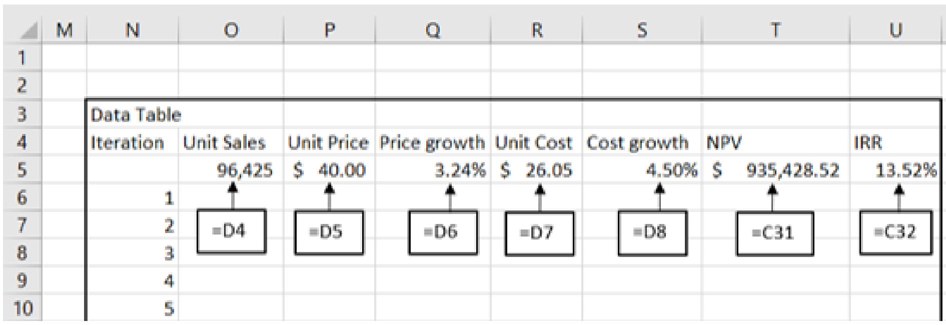
	A	B	C	D	E	F	G	H	I	J
1	Capital Budgeting Model									
2									Formulas in Column D	
3		Inputs				Expected	SD			
4		Unit Sales		138,300		120,000	12,000		=ROUND(NORM.INV(RAND(),F4,G4),0)	
5		Initial Unit Price		$ 40.00						
6		Annual Growth in Price		3.57%		3.00%	0.50%		=ROUND(NORM.INV(RAND(),F6,G6),4)	
7		Initial Unit Cost		$ 23.76		$ 26.00	$ 3.00		=ROUND(NORM.INV(RAND(),F7,G7),2)	
8		Annual Growth in Cost		4.10%		4.00%	0.50%		=ROUND(NORM.INV(RAND(),F8,G8),4)	
9		Fixed costs		$ 500,000.00						
10		Taxes		30%						
11										
12		Initial Investment		$ 4,500,000.00						
13		Depreciable Life		10						
14		Estimated Salvage Price		$ 1,503,125.81		$ 2,000,000.00	$ 500,000.00		=ROUND(NORM.INV(RAND(),F14,G14),2)	
15										
16		Required return		10%						

The uncertainty measures could be standard deviations for normally distributed factors or limits of the possible range of uniformly distributed random variables.[5] For our example, they are treated as standard deviations. The formula for Unit Sales would be =ROUND(NORM.INV(RAND(),F4,G4),0).[6] This calculates the number of units, rounded to the nearest whole unit, using a normal distribution with a mean equal to the value in cell F4 and a standard deviation equal to the value in cell G4. The formulas for other input factors would be similar but would reference values from their own rows. Units are rounded to the nearest whole number, dollar amounts to the nearest penny, and growth rates to the nearest hundredth of a percent.

Under the default recalculation option in Excel, the results generated by these formulas change every time a new value is typed into a cell or the user presses the F9 key to trigger a manual calculation. Excel treats a data table entering a value from the input list into the input cell in the same way as it does a user typing in a value. Therefore, the random functions all recalculate every time Excel enters a new input value in the data table. This Excel behavior can be used to facilitate simulations. The easiest (and cleanest) way to implement this is to create a list of values from 1 to N (with N being the number of desired iterations of the model) as the left-most column of the data table and then point the column input cell in the Data Table dialog box to an empty cell (i.e. to an input cell that is not used in the model itself). Every time Excel inputs the iteration number into the empty cell, it forces recalculation of the input formulas, so they reflect new draws from their respective probability distributions. That way, the recalculation will occur, but the model results will not be a function of the iteration number.

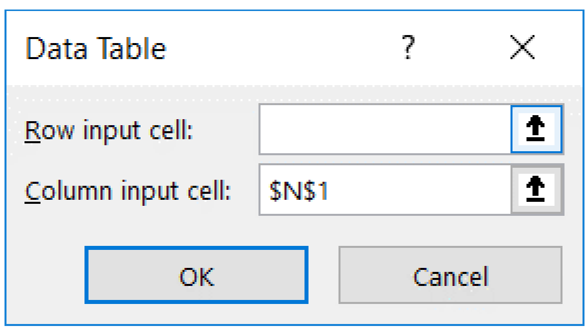
Figure 13 illustrates this approach for our example model. It is set up with a column of Iteration, going from 1 to 5,000 in the left-most column, and link formulas for the desired outputs (Unit Sales (Cell D4), Unit Price (Cell D5), Price Growth Rates (Cell D6), Unit Cost (Cell D7), Cost growth (Cell D8), NPV (Cell C31), and IRR (Cell C32)) in the top row. The input variables are included in case it is desirable to see what values were used to generate each NPV and IRR (or to verify that the mean and standard deviation match the original parameters specified for each probability distribution). Links to intermediate results, such as the Cash Flows for individual years, can also be added as additional columns, if desired.

Figure 13. Data table with results for each iteration



After highlighting the table range, N5:U5005, call up the Data Table dialog box. As discussed above, to ensure that the Iteration number in Column N doesn't affect anything in the model, point it towards an empty, unused cell, like N1, as the Column input cell, as shown in Figure 14.

Figure 14. Using empty cell as Column input cell



As Excel enters the iteration number for each row of the table into this cell, it causes Excel to recalculate formulas, including those that are based on RAND() functions. In this way, the randomized values for each input factor are renewed for each iteration. An example of the first ten iterations of the simulation results is shown in Figure 15.

Figure 15. Simulation results using a data table

	M	N	O	P	Q	R	S	T	U
1									
2									
3		Data Table							
4		Iteration	Unit Sales	Unit Price	Price growth	Unit Cost	Cost growth	NPV	IRR
5			138,300	$ 40.00	3.57%	$ 23.76	4.10%	$ 2,748,331.73	19.10%
6		1	121,675	$ 40.00	2.42%	$ 28.14	4.19%	$ (93,311.94)	9.62%
7		2	138,529	$ 40.00	3.46%	$ 25.41	4.55%	$ 1,838,442.22	16.46%
8		3	128,428	$ 40.00	2.14%	$ 21.75	3.91%	$ 2,913,658.88	19.54%
9		4	104,562	$ 40.00	3.16%	$ 26.58	3.05%	$ (66,798.32)	9.73%
10		5	111,954	$ 40.00	3.13%	$ 24.88	3.60%	$ 1,142,192.36	14.23%
11		6	124,221	$ 40.00	2.78%	$ 30.47	3.63%	$ (949,467.98)	5.74%
12		7	103,226	$ 40.00	2.52%	$ 29.80	3.43%	$ (1,177,689.53)	4.58%
13		8	119,318	$ 40.00	2.88%	$ 29.18	3.90%	$ (666,435.90)	7.10%
14		9	121,973	$ 40.00	3.50%	$ 25.88	3.93%	$ 1,515,498.93	15.45%
15		10	134,192	$ 40.00	2.76%	$ 28.14	3.85%	$ 506,761.14	11.97%

After Excel generates the data table with results from 5,000 iterations, the last step is to calculate summary statistics to help with interpreting the results. Figure 16 presents the mean, standard deviation, minimum, and maximum of the NPV and IRR calculations and the percentage of iterations where a positive NPV is obtained.[7] The formula to find this percentage uses COUNTIF() to find the number of positive NPVs and then divides by the COUNT() to convert to a percentage.

Figure 16. Summary statistics from simulation results

	W	X	Y	Z	AA	AB
1						
2						
3		Summary of Results				
4			NPV	IRR		Formulas for NPV column
5		Mean	$ 869,655.38	12.75%		=AVERAGE(T6:T5005)
6		SD	$ 1,350,207.31	5.02%		=STDEV.S(T6:T5005)
7		Pr(NPV>0)	73.48%			=COUNTIF(T6:T5005,">0")/COUNT(T6:T5005)
8		Minimum	$ (3,567,194.88)	-15.38%		=MIN(T6:T5005)
9		Maximum	$ 6,397,163.07	27.47%		=MAX(T6:T5005)

This summary details the NPV and IRR distributions for a given set of input distributions and would provide answers for Question 3 in the example in the Appendix. It could easily be repeated using alternate sets of distributions and leads easily into a discussion of how these alternate distributions affect the distribution of our measures of interest (i.e. IRR and NPV). These changes in distributions can then be used to facilitate class discussion on how changes in assumptions affect the riskiness of the project. Note that the results of the simulation will change slightly each time it is redone. To save individual iterations and summary results of a particular simulation, use Copy / Paste Special as Values to store them in a fresh location.

Answering Questions 4 and 5 in the Appendix example would require multiple simulations with different price levels. Figure 17 illustrates one possible setup for this: a two-way data table with the NPV in the upper left cell, the iteration numbers in the left-most column, and a set of prices in the top-most row.

Figure 17. Multiple simulations using a two-way data table

	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX
1											
2											
3											
4											
5											
6											
7											
8		Data Table		Price							
9		NPV	$ 369,836.25	$ 40.00	$ 41.00	$ 42.00	$ 43.00	$ 44.00	$ 45.00	$ 46.00	$ 47.00
10		Iteration	1								
11			2								
12			3								
13			4								
14			5								
15			6								
16			7								
17			8								
18			9								
19			10								

When the data table is complete, each column represents a separate set of simulations, each based upon its own price level. Figure 18 presents summary statistics for NPV for each price level. These results suggest that the price will have to be set to $41 or more to generate at least a 75% probability of a positive expected NPV (Question 4). Additionally, a price of $42 generates the highest expected NPV (Question 5) although the expected NPV for a price of $43 is very close behind and has a higher probability of generating a positive NPV. Of course, if the data table is recalculated, the results might be slightly different.

Figure 18. Results and summary statistics from multiple simulations

	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX
1			Mean	$ 919,180.14	$ 933,353.03	$ 968,002.61	$ 949,746.51	$ 896,889.92	$ 750,855.34	$ 595,496.85	$ 390,640.17
2			SD	$ 1,342,529.36	$ 1,265,634.56	$ 1,227,014.65	$ 1,153,998.46	$ 1,106,622.34	$ 1,015,542.17	$ 950,666.99	$ 892,705.31
3			Pr(NPV>0)	74.56%	76.98%	77.66%	79.72%	78.68%	76.16%	72.28%	65.52%
4			Minimum	$ (3,728,916.47)	$ (4,031,174.54)	$ (2,845,532.74)	$ (3,085,304.68)	$ (2,567,688.39)	$ (2,548,510.13)	$ (2,498,212.39)	$ (2,323,660.74)
5			Maximum	$ 7,900,930.15	$ 5,901,540.47	$ 6,247,653.38	$ 5,439,099.37	$ 5,403,154.26	$ 4,948,590.95	$ 4,618,382.25	$ 4,519,834.27
6											
7											
8		Data Table		Price							
9		NPV	$ (1,612,318.41)	$ 40.00	$ 41.00	$ 42.00	$ 43.00	$ 44.00	$ 45.00	$ 46.00	$ 47.00
10		Iteration	1	$ 38,082.84	$ (130,249.26)	$ 1,854,841.85	$ 1,768,329.36	$ 1,398,804.55	$ 856,086.83	$ 983,744.66	$ 1,044,635.11
11			2	$ 785,171.62	$ 1,640,311.86	$ 1,423,122.48	$ 1,793,040.14	$ (425,743.20)	$ 1,350,961.99	$ 1,720,933.47	$ 1,049,028.90
12			3	$ (152,544.61)	$ 1,779,335.72	$ 2,428,345.35	$ 867,298.35	$ 831,427.62	$ 147,735.07	$ (550,864.15)	$ 649,487.11
13			4	$ (1,040,314.88)	$ (734,455.75)	$ 1,198,905.71	$ 627,611.62	$ 742,444.42	$ 2,137,939.84	$ 57,398.86	$ 1,185,732.39
14			5	$ 2,106,778.32	$ (919,651.00)	$ (530,335.87)	$ (1,155,796.74)	$ 2,016,069.63	$ (1,926.56)	$ 1,663,746.69	$ 591,285.81
15			6	$ (766,474.85)	$ (943,950.69)	$ 1,820,581.61	$ 2,151,755.23	$ 2,125,140.84	$ (975,026.27)	$ (746,004.47)	$ 750,089.65
16			7	$ 105,349.24	$ (335,990.88)	$ 3,097,342.18	$ 1,058,719.53	$ 4,112,818.89	$ 993,116.39	$ 87,677.12	$ 1,380,848.05
17			8	$ 799,490.72	$ 3,595,530.71	$ 572,830.39	$ 1,881,994.27	$ 2,924,870.58	$ 710,965.33	$ 1,024,910.75	$ 176,608.60
18			9	$ 2,941,460.43	$ (722,079.03)	$ 809,020.04	$ 685,238.74	$ 115,320.18	$ 2,133,379.52	$ 602,327.17	$ 1,057,081.38
19			10	$ (147,757.58)	$ 991,813.38	$ 611,439.06	$ 1,445,073.84	$ (245,855.16)	$ 1,227,255.76	$ 328,267.76	$ 532,674.97

SUMMARY

This paper illustrates a method for using Excel's data tables to conduct sensitivity and simulation analyses without the need for technical programming skills like VBA or costly third-party software such as @Risk or Crystal Ball. The techniques are straightforward and allow students to focus on the underlying problem at hand and the impact of the assumptions on the base model. Students will be able to quickly learn and apply data tables to conduct sensitivity analyses. After a review of statistical measures appropriate for defining how to calculate a random outcome within a specified distribution, simulation analysis should be quickly within their reach.

This approach allows instructors to easily extend students' perspective of financial analysis beyond a simplistic, deterministic world. The use of data tables allows them to explore how changes in a model's assumptions can alter the results. This will give them a perspective that encompasses the role of uncertainty in modeling.

NOTES

1. One common mistake that students make is to create the list of input values using a formula that references the assumption cell, such placing as "=D5+2" in Cell L2 and then copying this down the column. This will cause the values in the input list to change each time a new value is entered in the assumption cell (D5) and will result in Excel generating results for different values than the ones actually shown in the list. The safest way to avoid this is to use either a formula that does not reference the assumption cell or to use fixed values, i.e. numbers typed in and not generated by a formula. Alternatively, you could use a formula to generate the values but then convert them into values using Copy / Paste Special as Value before creating the data table.
2. Part of the formatting may include hiding the link formulas. This could be done by hiding the row or column in a one-way table or setting the font of the upper left cell, the one containing the link formula in a two-way data table, to be white text. This will prevent the reader of a table from focusing on a number that is based on the base values of the model rather than the specific values explored in the data table.
3. Comparisons of equal standard deviations are more appropriate than using the same plus/minus factor because they consider the magnitudes of changes with similar probabilities.
4. At the time of this article, computing power is typically a non-binding constraint. Even simulations involving sample numbers of iterations in excess of 20,000 execute in a matter of seconds on typical student laptops. However, large spreadsheets with multiple large data tables could result in longer execution time because of the need for recalculation.
5. The uncertainty measure could also be a parameter such as a probability in a binomial distribution or λ, an arrival frequency, in a Poisson distribution.
6. The NORM.INV() function works similarly to the NORM.S.INV() function discussed previously except that it uses the mean and standard deviation specified in the arguments instead of the standard normal distribution.
7. Additionally, other Excel functions, such as SLOPE(), or tools within the Data Analysis Toolpak, such as the Histogram wizard, are also available to analyze the results. However, most of the tools in the Data Analysis Toolpak generate static results that will not update if the simulation is rerun. The functions that we show in Figure 16, along with others that are in the completed spreadsheet, are all dynamic.

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APPENDIX

Note: A copy of the completed spreadsheet is available from the authors upon request.

The managers at Cumberland Tool Co., Inc., are trying to decide whether to move ahead with a proposed new tool set product. The tool set will include some standard hand tools and some with innovative features. It will be offered for sale through typical hardware store outlets including big-box stores and local hardware retailers. Various groups within the company, including the marketing, operations, and finance groups, as well as an outside marketing consultant, have compiled the following information about the project.

The marketing research, which the outside consultant charged the firm $100,000 to conduct, estimates that the demand function will be $Q = 400{,}000 - 7{,}000P + \varepsilon$. The marketing group proposed a price of $40.00 per tool set. To produce the tool sets, the firm will need to acquire equipment that will cost $4,500,000 and will be depreciated straight-line over a 10-year economic life even though the project is expected to last only 6 years. The variable cost per tool set, including labor and materials, is estimated to be $26.00 while the fixed costs will be $500,000 per year. The price per unit is expected to grow at an annual rate of 3% while the variable costs will grow at 4% each year. At the end of the project's life, the equipment is expected to be sold for $2,000,000. The firm's tax rate is 30% and the firm's required return for projects of this level of risk is 10%.

Question 1: Does it make sense to move forward with this project? Support your recommendation with evidence from a financial model (i.e., NPV and IRR).

Part of the discussion by the firm's Capital Budgeting Committee centered on the uncertainty of the estimates used to value the project. Upon the request of the Committee, each of the constituents that contributed to the original proposal provided the following estimates of uncertainty:

Demand	10% of Q
Unit Cost	$3.00
Unit Price growth rate	0.50%
Unit Cost growth rate	0.50%
Estimated Salvage Value	$500,000

Question 2: Using sensitivity analysis, evaluate which factor influences the project's overall results the most. Use results from your data tables to support your explanation.

Question 3: Since there is variation in the possible values for the assumptions used in the model, there is likely to be variation in the final results. In hindsight, will your recommendation (Question 1) always be the correct decision? Using simulation analysis, estimate the probability that the project will generate a positive NPV, assuming that the firm continues to use an initial unit price of $40.00.

Question 4: The Capital Budgeting Committee has determined that it prefers only to accept projects with an expected probability of success of at least 75%. What is the minimum price that will meet the Committee's requirement? (Assume price increments of $1.00.)

Question 5: What price should the firm set on each tool set if it wishes to maximize the expected NPV? Compare the expected NPV and probability of success at this price level to those at nearby price levels. Is there a clear optimal price level for the firm to choose?