

6/17/04  
05:45

# **Computational Economics: Help for the Underestimated Undergraduate**

by

David A. Kendrick  
University of Texas

P. Ruben Mercado  
University of Texas and IDES

Hans M. Amman  
Technical University of Eindhoven

Abstract:

Our concern in this paper is that the capability of economics undergraduates is substantially underestimated in the design of the present college curriculum and that our students are insufficiently challenged and motivated. Students enter our classrooms with substantial previous knowledge about computers and computation and we are not taking full advantage of this opportunity.

We suggest a set of examples from computational economics which are challenging enough to motivate students and simple enough that they can master them within a few hours. By encouraging the students to modify the models in directions of their own interest, avenues for creative endeavor are opened which deeply involve the students in their own education.

The ubiquitous personal computer has filtered deeply through the lives of college undergraduates; however undergraduate education in economics has so far failed to take full advantage of this sweeping change. We are underestimating the learning ability and insufficiently challenging a whole generation of undergraduate students in economics. The thesis of this paper is that computational economics offers a way to improve this situation and to bring new life into the teaching of economics in colleges and universities.

With its early focus on algorithms, computational economics seemed well-suited for a relatively small group of graduate students and unlikely to have much impact on undergraduates. However, that is changing as we are discovering that computational economics provides an opportunity to move away from too much use of the lecture-exam paradigm and more use of a laboratory-paper paradigm in teaching undergraduate economics. This opens the door for more *creative* activity on the part of the students by giving them models developed by previous generations and challenging them to modify those models. The modifications can be altering the models to make them applicable to the student's interest or finding weaknesses in the model that can be strengthened by changes in the structure of the model. In the process the students become much more involved in their own education.

In this paper we provide examples from a number of fields of economics and discuss how they can be used to develop opportunities for students to learn about and then modify these computational models.<sup>1</sup>

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<sup>1</sup> A number of books about computational economics are available. Two of the early ones were GAMS-based (Thompson and Thore (1992)) and Mathematica-based (Varian (1996)). Also a GAUSS-based book has recently been developed by Kuan Pin Lin (2001) for online use. A book with a numerical analysis orientation is Judd (1998) and a recent book on applied computational economics and finance is the MATLAB-based book of Miranda and Fackler (2002). We are currently working on an undergraduate/graduate book for computational economics students that uses a variety of software systems including GAMS, Mathematica, Excel, GAUSS, Access, Duali and MATLAB viz. Kendrick, Mercado and Amman (2004).

## 1. Growth Theory

Most undergraduates encounter growth theory in sophomore level macroeconomic courses. Since ordinarily only analytical and not computational methods are used, the discussion is restricted to the properties of the steady state solution to the model. However, every politician knows that what people really care about is the growth of the economy in the next few quarters and not the growth in the indefinite future when the steady state is reached.

It would seem difficult to teach nonlinear programming to undergraduates so that they can solve a growth model with a Cobb-Douglas production function, a capital accumulation equation and a nonlinear welfare function. However, help is right under our noses in the form of Excel. Almost all undergraduates are familiar with Excel and it has embedded within it a tool called the Solver which can be used to compute the solution to nonlinear programming models. The famous Ramsey model is easily cast in this form and a student can quickly be doing experiments to study the effects of changes in the discount rate on the time path of consumption in the next few years.

The student does not need to understand the complexities of reduced gradient methods for solving nonlinear programming problems in order to gain a fine appreciation of growth theory. Rather the Solver permits the student to focus on the economics of growth theory rather than on the mathematical and computational methods that are used to solve the model. Also, the student is free in Excel to deviate from the “standard” Ramsey model and apply more complex nonlinear structures.

Figure 1 provides a screen shot of a nine period growth model in Excel from Chapter 2 of Kendrick, Mercado and Amman (2004). Line 9 shows the capital accumulation which begins at 7.0 in period 0 and grows to 9.1 in period 9. The two lines above this show the corresponding consumption and production in each of the time periods. The utility in each period is shown in line 12 and the total discounted utility is computed in cell L12.

|    | A            | B     | C     | D     | E     | F     | G     | H     | I     | J     | K     | L      |
|----|--------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| 1  | Growth Model |       |       |       |       |       |       |       |       |       |       |        |
| 2  |              |       |       |       |       |       |       |       |       |       |       |        |
| 3  |              |       |       |       |       |       |       |       |       |       |       |        |
| 4  | Time Period  | 0     | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     |        |
| 5  | Consumption  | 0.347 | 0.351 | 0.355 | 0.358 | 0.361 | 0.364 | 0.366 | 0.368 | 0.370 |       |        |
| 6  | Production   | 0.570 | 0.576 | 0.582 | 0.588 | 0.594 | 0.599 | 0.605 | 0.611 | 0.616 |       |        |
| 7  |              |       |       |       |       |       |       |       |       |       |       |        |
| 8  |              |       |       |       |       |       |       |       |       |       |       | Target |
| 9  | Capital      | 7.000 | 7.223 | 7.448 | 7.676 | 7.906 | 8.138 | 8.373 | 8.612 | 8.854 | 9.100 | 9.100  |
| 10 |              |       |       |       |       |       |       |       |       |       |       |        |
| 11 |              |       |       |       |       |       |       |       |       |       |       | Total  |
| 12 | Utility      | 1.178 | 1.161 | 1.144 | 1.126 | 1.108 | 1.090 | 1.072 | 1.054 | 1.035 |       | 9.970  |
| 13 |              |       |       |       |       |       |       |       |       |       |       |        |
| 14 |              |       |       |       |       |       |       |       |       |       |       |        |
| 15 |              |       |       |       |       |       |       |       |       |       |       |        |
| 16 | tau          | 0.5   |       |       |       |       |       |       |       |       |       |        |
| 17 | beta         | 0.98  |       |       |       |       |       |       |       |       |       |        |
| 18 | alpha        | 0.33  |       |       |       |       |       |       |       |       |       |        |
| 19 | theta        | 0.3   |       |       |       |       |       |       |       |       |       |        |

Figure 1 A Growth Model in Excel

The model shown in Fig. 1 is solved by selecting the Solver option on the Tools menu which causes the Solver Parameters dialog box to appear as shown in Fig. 2.

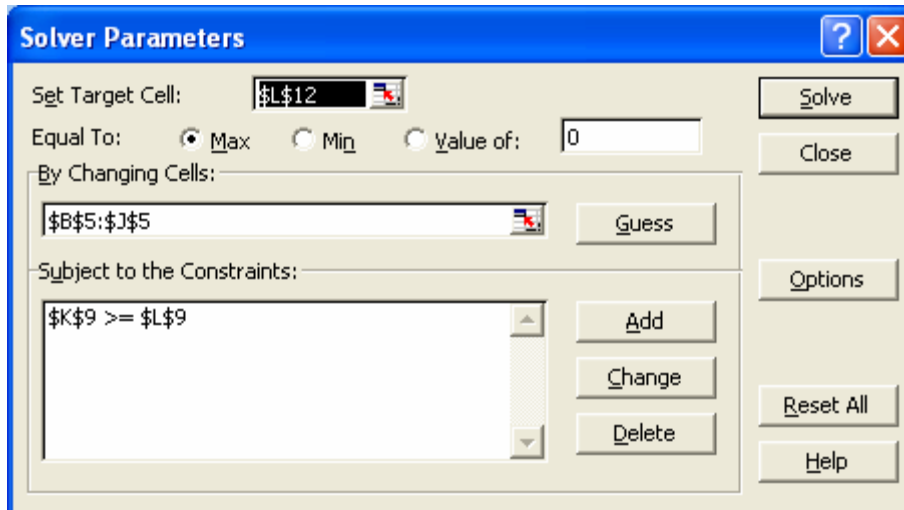


Figure 2 The Solver Dialog Box in Excel

This dialog box shows that the cell to be maximized is L12 (total discounted utility) and this is to be done by choosing the optimum consumption levels in cells B5 thru J5. This is to be done while assuring that the terminal capital stock in period 9 (in cell K9) is greater than or equal to the exogenously specified target capital stock (in cell L9).

The use of Excel to teach growth models has the virtue that the interface is familiar to most economics undergraduates and yet just underlying this familiar interface is a powerful nonlinear programming solver.

## 2. Macroeconomics

A second example is from macroeconomic fluctuations. Many students learn graphical ways of manipulating small macroeconomic models with consumption, investment and money demand functions. Most also learn the basic mathematics underlying the multiplier. However, few students advance to the accelerator in the investment equation because its specification requires the use of difference equations which are thought to be beyond the capability of most economics undergraduates. Also, students are sometimes exposed to numerical macroeconomic models but these are encapsulated in packaged software that becomes a black box with inputs and output but without an option for the students to see what is inside the box.

In contrast, students can be taught to solve small macroeconomic models like the one in Hall and Taylor (1997) in a high level computer language like GAMS<sup>2</sup> in which they can see all the equations and parameters and realize that they have the ability to modify the structure of the model.<sup>3</sup> The section below shows a slightly modified version of three of the twelve equations from this model in GAMS. The set of time periods includes periods 0 thru 15 and there are three scalar parameters. Also this small portion of the model includes the GDP identity, the disposable income equation and the consumption equation.

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SETS
T          extended horizon          / 0*15 /

SCALARS
a          minimum consumption       / 220 /
b          marg prop to consume      / 0.7754 /
tax        tax rate                  / 0.1875 /

VARIABLES
Y(T)      gdp
Yd(T)     disposable income
C(T)      consumption

EQUATIONS
eq1(T)    gdp identity
eq2(T)    disposable income
eq3(T)    consumption

eq1(T)..  Y(T)   =E=   C(T) + I(T) + G(T) + X(T) ;

eq2(T)..  Yd(T)  =E=   (1 - tax) * Y(T) ;

eq3(T)..  C(T)   =E=   a + b * Yd(T) ;

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Experimenting with this kind of a macroeconomic model in a set-driven algebraic software system like GAMS enables the students to gain experience with compilers and to learn how to modify the model in ways that make the results more interesting from their own perspective.

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<sup>2</sup> Brooke, Kendrick, Meeraus and Raman (1998).

<sup>3</sup> See for example Mercado, Kendrick and Amman (1998).

An example is that the usual sophomore level macroeconomic model has a steady state that the economy always returns to after an external shock. In contrast, in the real economy investment is constantly augmenting the capital stock so the potential output level, and thus the steady state, is constantly changing. A student can modify the GAMS version of the model by adding a production function and a capital accumulation equation and soon have a much more realistic model of the economy.

A different modification to the basic textbook model would be for the student to add a wealth term to the consumption function and create a stock price equation driven by income and interest rates. Then the model can be used to simulate the “irrational exuberance” which so concerned Alan Greenspan during the bubble of the late 90’s.

In the process of making alterations like these the students gain something that is perhaps the most valuable of all – a confidence that they understand the economic model in depth and can modify it to reflect their own interest or political point of view.

### **3. Financial Planning**

Many students face a difficult economic problem – how to balance borrowing from student loan funds and from credit cards to finance their education without having to work too many hours at part time jobs. This situation can be captured in a simple dynamic model of student finances.

The model has state equations for a checking account, a credit card and student loans. It also has state equations for stocks and bonds in case the student is fortunate to have some of these. The checking account equation includes terms for income from a part time job and expenses for room, board and tuition. Interest rates are added to the state equation to reflect the low rates on student loans and the high rates on credit card loans. A quadratic tracking criterion function is specified to include desired paths for the checking account, for student and credit card loans, and for stocks and bonds. Initial conditions for the model reflect the student’s present financial condition, which in the present era frequently features substantial credit card debt along with some student loans and a modest checking account balance.

A model of this sort can become a wonderful, and highly motivating, laboratory for the students to gain some appreciation of the dynamics of their own financial situation. In the process they learn how to develop difference equation models in a computational framework and to solve these as optimization problems.<sup>4</sup>

#### **4. Game Theory**

Game theory is mostly taught to undergraduates using analytical methods which enable the students to examine equilibrium solutions to models. In the past it was difficult to use computational methods in this field because most software systems were not able to manipulate analytical mathematics. However, the Mathematica<sup>5</sup> software permits the user to input functional forms and then take the analytical derivatives. This provides a wonderful bridge from chalk and the blackboard to the computer laboratory.

Cournot, Stackelberg and monopoly versions of models can be input to Mathematica. The derivative can be taken and displayed and the nonlinear first order conditions solved to provide the analytical solution. Parameters can then be added and the models can be solved to show the difference between output and profit levels for the two firms in the different versions of the model.

#### **5. Environmental Modeling**

A model developed by William Nordhaus (1992) on the global warming problem provides a good starting point for environmental modeling. This model has about ten equations including a production function and a capital accumulation equation. It also includes an emission equation and an atmospheric accumulation equation for  $CO_2$ . This accumulation in turn drives temperature changes which impact on output levels. In addition the model includes a variable which is like a carbon tax and which can be used to reduce  $CO_2$  emissions. However, this carbon tax results in inefficiencies which tend

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<sup>4</sup> For an example student financial model in GAMS see the chapter on this subject in Kendrick, Mercado and Amman (2004). Also financial models like this are readily developed in Excel.

<sup>5</sup> Wolfram (1991) and Varian (1996).



to reduce output. So the basic tradeoff in the model is between using the carbon taxes to reduce emissions and thus global warming and the detrimental effects of these taxes on efficiency and therefore output.

As a dynamic nonlinear problem with ten equations one would expect that it would be well beyond the reach of most undergraduates. However, once the students learn the basics of growth models using the Excel Solver discussed above, they are no longer intimidated by either growth models or nonlinear programming. Thus they are in a position to understand how equations for  $CO_2$  accumulation and temperature change can be added to a growth model to convert it to a global warming model.

Once they understand the model the students are in a strong position to modify it according to their own point of view. For example an optimist might increase the parameter which reflects the ability of the atmosphere to breakdown  $CO_2$  so that output can continue to rise rapidly without much of an increase in global temperatures. In contrast, a pessimist might increase the parameter that represents the ratio of carbon emissions to the level of output and see how that change requires even higher carbon taxes to reach environmental goals.

The important development for the student here is the realization that they are in control of the model and that they can modify it to reflect their own interest. This can release real creative energy among students.

## **6. Neural Nets**

Neural net estimation is basically a nonlinear optimization problem and can be formulated and solved using the Solver in Excel the same as the growth model discussed above. Excel provides a familiar environment in which to arrange the data, display the results and perform “outside of sample” predications. An example from the stock market provides good motivation for most students. A model can be developed to predict the price of an automobile company stock using as independent variables the price of its competitors’ stocks at one hidden node and the price of its suppliers’ stocks at a second hidden node.

Since neural net estimation can result in nonconvex criterion functions, their use provides a good opportunity for the students to learn about the pitfalls of local optima in optimization problems. This in turn is a substantial step toward realizing that the second order conditions are not satisfied in all economic models such as production models in which there are economies of scale. Moreover, it helps them to realize that computational methods can be used to search for the best local optima in such cases.

While most economic students are motivated by financial examples of neural net applications some are more attracted to professional sports – where great amounts of money are also at stake. One student decided to modify the automobile stock market model to instead predict the point spread in professional basketball games. He assiduously collected offensive and defensive statistics for the teams and then regaled his fellow students with his prowess at predicting the outcome for playoff games.

## **7. Relational Database Systems**

Though database systems are routinely taught to business and to computer science students they are not usually included in the undergraduate economics curriculum. This is a loss for the students. While econometric tools are most useful for data analysis, problems frequently arise in economics where a quick and dirty look at the data provides a good start point in understanding the underlying relationships. Moreover, the Access database system is widely available and its user interface is so intuitive that the students easily master the fundamentals of making joins across relations and thus move into position to harness the power of database systems.

We use an example database with commodities, plants, production processes, unions, companies, cities, state, regions, governors and political parties to give the students a start at appreciating the power of relational database systems. We then encourage them to “roll their own” and find that students respond well to this opportunity. One student who was working as a waitress in a lakeside restaurant developed her own database system to keep track of what her customers ordered, the specials that night, the prices of the items on the menu, the day of the week, the advertising and her tips. She quickly found that she could predict some of the tipping pattern of her customers and then moved on to begin advising the manager of the restaurant about pricing, specials and advertising.

## **8. Optimal Portfolios with Mean-Variance Analysis**

Dating from the work of Markowitz (1952) financial advisors have used the fundamental mean-variance tradeoff in a quadratic programming framework to help clients construct optimal stock portfolios. A computational model to do this can be developed in MATLAB<sup>6</sup> by inputting the mean returns as a vector and the corresponding covariance as a matrix. The vector and matrix can then be passed to a subroutine in the MATLAB Optimization Toolbox and solved for the best portfolio.

This provides a fine opportunity for students to understand the importance of negative covariances between assets in a portfolio and thus to construct serviceable portfolio from stocks and bonds of their own selection. It also provides a good example of the strengths of MATLAB and its associated Toolboxes.

While most of the other examples discussed in this paper use high level computer languages this example moves toward a lower level language. MATLAB is for the present generation what FORTRAN was for the previous generation – a highly versatile language which can be used to program the solution for almost any economic model.

## **9. Conclusions**

Our concern is that the capability of economics undergraduates is substantially underestimated in the design of the present college curriculum and that our students are insufficiently challenged and motivated. Students enter our classrooms these days with substantial previous knowledge about computers and computation and we are not taking full advantage of this opportunity.

We suggest in this paper a set of examples from computational economics that are challenging enough to motivate students and simple enough that they can master them within a few hours. By encouraging the students to modify the models in directions of their own interest, avenues for creative endeavor are opened that deeply involve the students in their own education.

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<sup>6</sup> Math Works (2000) and Miranda and Fackler (2002).

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