

## ***MacroLab Lite* for Introductory Macroeconomics**

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### **Purpose of this Paper**

*MacroLab* is a comprehensive system dynamics-based macroeconomics model that has evolved considerably since its origin at the turn of the century. It was originally conceived as a simple teaching tool for use in my macroeconomics principles course at Virginia Western Community College in the United States. The earliest versions were designed for hands-on student use and emphasized constructive learning: 'learn by building.' Most of those students would never take a second course in economics. In their later lives, when unemployment, inflation, or financial crises made front page news, I wanted them to have a useful framework to organize their thoughts about those events and think critically about the response of economic policy makers.

Alas, the model grew like topsy during my dissertation project and, by the time it was published in 2007, the stock-and-flow structure was much more complex. Sure, my first-year undergraduates could still push a button and observe the model's behavior on a graph. And, for many students, the interface of the model had a video game feel about it; they liked playing with the toy economy. But I could sense a diminishing grasp of underlying structure as the students lost touch with the stocks and flows. And that distance widened over the next fifteen years. Opportunities to use *MacroLab* with many advanced graduate students and a few policy makers in Europe led to even more complexity due to their higher theoretical and empirical expectations. That was rewarding, of course, but I did regret the growing gap between the original *MacroLab* motivation and its evolving use. This paper describes an effort to fill that gap with a 'lite' version for introductory macroeconomics.

Three principles are guiding the design of *MacroLab Lite*. The first is that *Lite's* simpler structure should be recognizably similar to the full version. Anyone ready to make the transition from one version to the other should be comfortable with the move and find familiar territory along the way. The transition should take advantage of the emotional comfort and motivation that comes from connecting new information to what one already knows. The closely related second principle is that *Lite's* construction should require only simple arithmetic and only a few *types* of equations. I want a student modeler to see the payoff from learning to use a few modeling tools correctly. The third principle will come as no surprise to system dynamics modelers. The similar but simpler structure of *MacroLab Lite* should generate behavior that, in the aggregate, is similar to the behavior of the full version, and for similar reasons.<sup>1</sup>

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<sup>1</sup> As this is written four months before the conference, simplification is complete on the supply side of the model and that is the focus of this paper. Application of the same principles to the demand side has begun, and an update is planned for discussion at the conference.

### Similar Structure with Simpler and Fewer Equations

An enduring feature of *MacroLab* has been the feedback relationship between the Supply Side and Demand Side of the domestic economy, as well as between the domestic economy and international trading partners – the ‘rest of the world.’ Recently, a third component—the financial sector — has been moved to the top level, front and center. Originally contained within the Demand Side, the central bank and commercial banks are now more prominent. A comparison of the top level of *MacroLab Lite* and today’s full version would reveal no differences; both can be represented by the diagram in Figure 1.

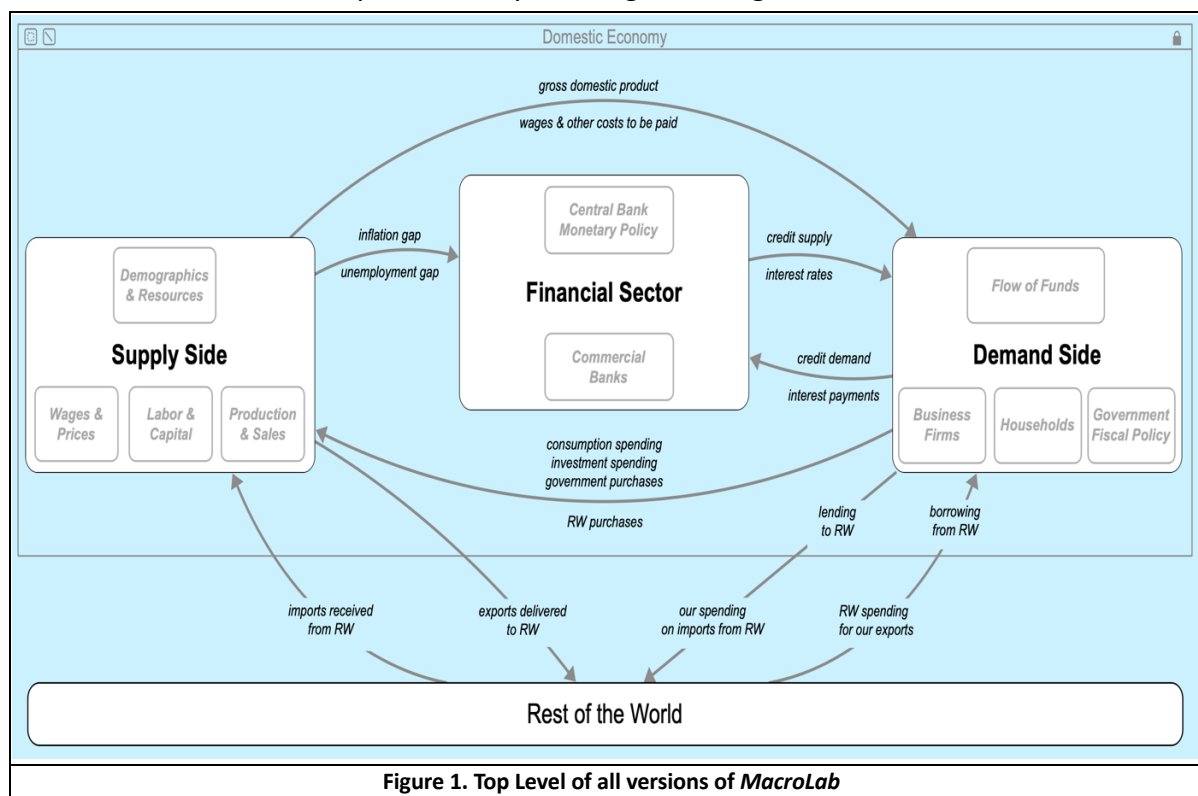


Figure 1. Top Level of all versions of *MacroLab*

Users of isee systems’ *Stella Architect* software (<https://iseesystems.com>) recognize the oval-shaped figures as modules that contain sub-models. The Supply Side, for example, contains four sub-models: Production & Sales, Labor & Capital, Wages & Prices, and Demographics & Resources. The arrows connecting the modules are ‘bundles’ of transmitted information about multiple variables within one module that are inputs to equations in other modules. The annotation added to Figure 1 – the labels on the modules and the text along the connecting arrows—are simply visual aids for the user. In an introductory course, students encounter this diagram in various course materials, and it’s intended to serve as a useful summary of the structure of the overall course.

While the organization of structure does not vary between *MacroLab* versions, the content of the sub-models is simpler in the *Lite* version. The number of equations is one useful metric for comparison. In the single-industry full version of *MacroLab*, the main Labor & Capital structure (not counting data, initial values, and side calculations) consists of 65 equations, while the corresponding structure in the *Lite* version has 18 equations. The other sub-models on the Supply Side are even simpler: the largest contains only 19 essential variables, meaning that students can build each sub-model in *Stella Online*, the free version of the software.

Not only does the *Lite* version have fewer equations, it has fewer *types* of equations. In the Labor & Capital sub-model, for example, half of *Lite's* equations make use of percentage growth rates, and almost all the rest require the simplest arithmetic operations. There are no goal-seeking equations requiring adjustment time division of a difference between a stock and its goal, with the attendant interpretation issues on top of the arrangement of the variables within the equation. Of course, the full version contains greater diversity of equations with a more nuanced operational interpretation, but that comes with a corresponding cognitive burden. *Lite* is more student friendly.<sup>2</sup>

### Overview of the Supply Side.

Figure 2 displays the four sub-models on the Supply Side. The details of each sub-model are discussed later. Here, the high-level supply side story is implicit in the connections among the sub-models.

Begin at the top right corner of the diagram, where nominal aggregate demand is an input to the Production & Sales (PS) sub-model from the Flow of Funds sub-model on the Demand Side. Within the PS sub-model, GDP is determined, based on sub-model structure and the inputs from other sub-models. The PS sub-model sends information about real AD and capacity utilization to the Labor & Capital (LC) sub-model, where decisions determine production capacity and return its value to the PS sub-model. At the same time, the LC sub-model is determining labor productivity (output per worker) and the employment rate, then transmitting information about both to the Wage & Price sub-model, the output of which is the price index that converts nominal AD into real AD inside the PS sub-model.<sup>3</sup>

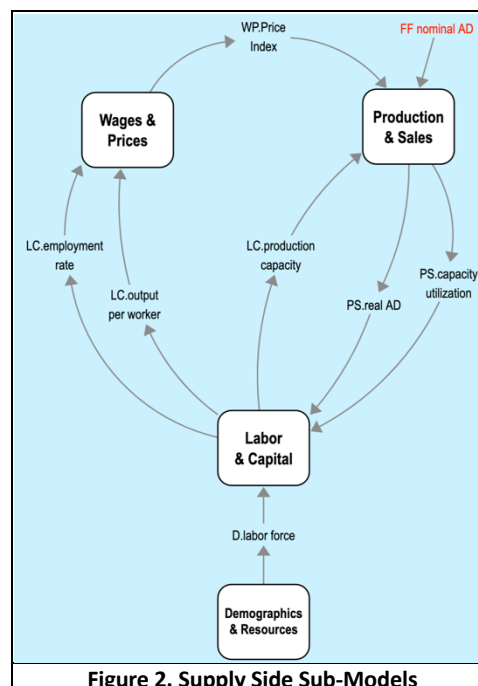


Figure 2. Supply Side Sub-Models

<sup>2</sup> It is well known that many undergraduate students in the U.S. have weak math skills. Calculation and interpretation of percentages (both as fractional relationships and measures of change) seem to be especially challenging for those students. Early in the introductory course, all students are required to brush up on their 'percent skills,' and they are provided with many opportunities to practice the calculations and interpretations and become comfortable working with equations involving annual growth rates.

<sup>3</sup> This high-level story is intended to be a teaser. It provides only a slender framework for thinking about the Supply Side production process. Fortunately, even some first-year students are motivated to think about what goes on inside the oval-shaped modules. What do they think is happening? Before revealing the details of each sub-model, an instructive exercise is to get students brainstorming with pencil and paper (or *Stella*).

**Production & Sales Sub-Model.** The arrival of information about nominal Aggregate Demand from the Demand Side activates the Production & Sales (PS) sub-model. There, division by the price index determines how much is actually purchased; i.e., it converts nominal AD to real AD. The sub-model is displayed in Figure 3, and the equations are listed in the appendix. Variables colored red are inputs from other parts of the model, and the 2-letter prefix indicates the source sub-model (Price Index from Wages & Prices, nominal AD from Flow of Funds, and production capacity from Labor & Capital).

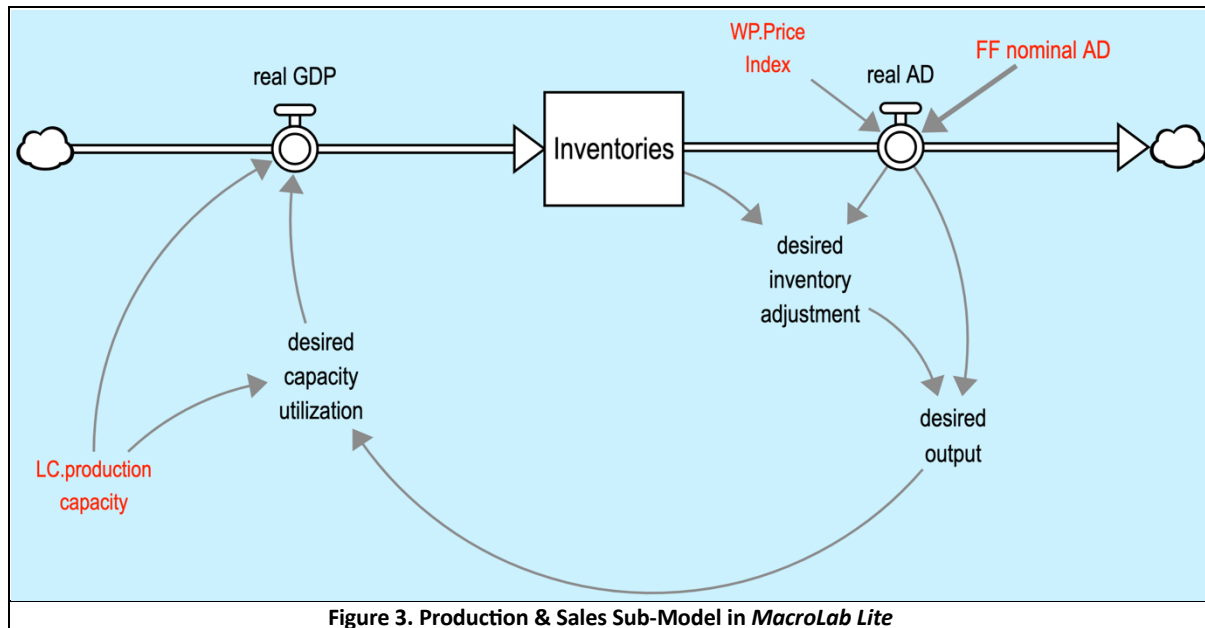


Figure 3. Production & Sales Sub-Model in *MacroLab Lite*

The behavioral hypothesis in the PS sub-model is that, to the extent production managers can adjust capacity utilization, their strategy is to satisfy aggregate demand. Since ‘desired capacity utilization’ is defined so that real GDP equals desired output, that hypothesis is self-fulfilling (as is necessarily true of an internally consistent causal model). Nevertheless, if the model’s Price Index variable fails to mimic actual price behavior, both real AD and real GDP (and capacity utilization) will be error-prone relative to the empirical evidence.

The advanced version of *MacroLab* can be structured as a multi-industry or single-industry model. In the multi-industry version, production aims to satisfy both final demand and intermediate demand.<sup>4</sup> There are multiple PS sub-models, one for each industry specified in the model. In addition, each PS sub-model contains its own embedded sub-model that accounts for the inputs received by that industry from all the other industries, as well as imports. That requires the PS sub-model to distinguish between production and GDP. Specifically, the value of inter-industry inputs and imports that contribute to the production process are subtracted from production to derive value added for each industry, and GDP is the sum of the value added by each industry. Even the single industry version keeps track of imports, and GDP is the difference between the value of production and the value of imports; stated differently, production = GDP + imports.

<sup>4</sup> Final demand includes household consumption and residential investment, business investment in structures and equipment, government purchases, and export demand. Intermediate demand includes purchases by other industries for services and materials used in their production and sales processes.

The *Lite* version is also single industry model, but there is no accounting for imports within the PS sub-model. Instead of adding imports to GDP on the Supply Side of the model, imports are subtracted from Aggregate Demand on the Demand Side of the model. This is consistent with the standard textbook equation (and national accounting convention) that  $AD = \text{consumption} + \text{investment} + \text{government purchases} + (\text{exports} - \text{imports})$ , as if domestic consumers were regularly engaged in foreign transactions to acquire goods and services. At the end of the modeling day, the math is the same and we resist quibbling about the  $AD = C+I+G+(X-M)$ . equation every time it appears in the textbook.<sup>5</sup>

**Labor & Capital Sub-Model.** Figure 4 displays *Lite's* Labor & Capital (LC) sub-model, where decisions are made regarding the acquisition of capital and labor that jointly determine production capacity. Over time, growth in production capacity tracks growth in aggregate demand. The equations are listed in the appendix.

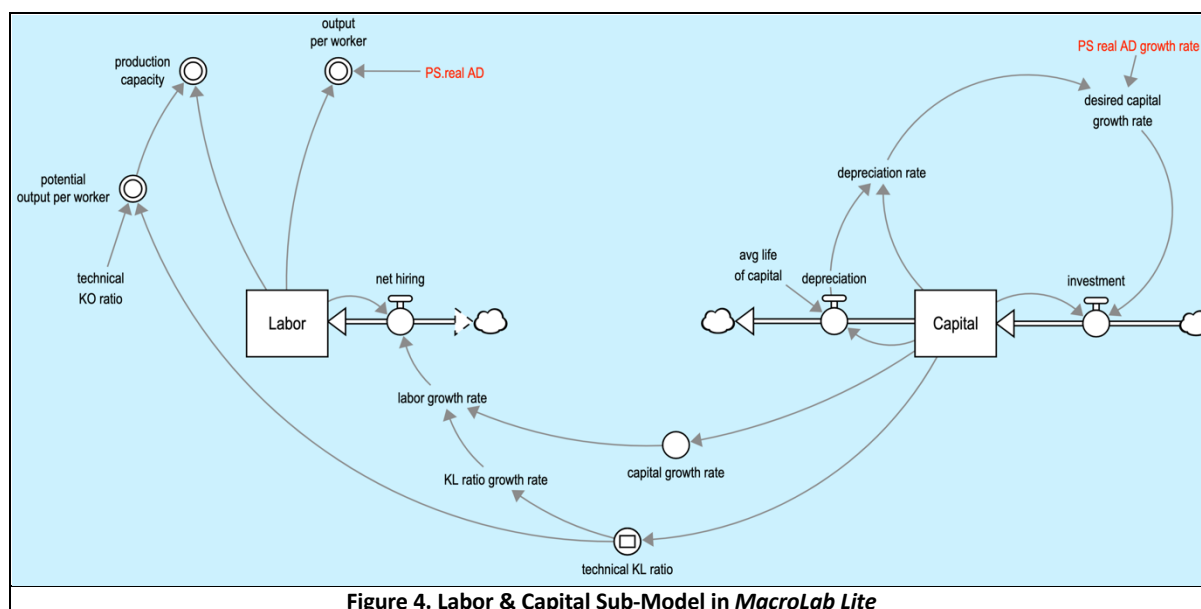


Figure 4. Labor & Capital Sub-Model in *MacroLab Lite*

The desired capital growth rate is the sum of the real AD growth rate and the depreciation rate. In turn, the labor growth rate is the difference between the growth rates of capital and the capital-labor (KL) ratio. As noted previously, if students are to grasp the interpretations inherent in four successive percentage growth equations, they must be well drilled in percentage-based math. The payoff comes when they encounter many familiar equations.

The behavioral hypothesis stems from a simple identity:  $\text{labor} = \text{capital} / \text{capital-labor ratio}$ . The equation could be interpreted as a mere tautology. However, the capital-labor ratio in the model is modeled apart from the labor stock and has an engineering interpretation. Empirically, it exhibits a strong correlation with changes in the capital stock (when adjusted for capacity utilization).

<sup>5</sup> In the multi-industry version of *MacroLab*, we use the concept of Gross Final Demand, defined as  $C+I+G+X$  and, as noted in the text,  $GDP = \text{production} - \text{intermediate inputs} - \text{imports}$ .

A similar regularity can be observed between the capital-output (KO) ratio and changes in real AD (again, adjusted for capacity utilization). Both are reminiscent of Verdoorn’s Law (see Verdoorn (1949) and Knell (2004)). In the 1990-2018 U.S. data, the change in both ratios is roughly proportional to the square root of the percentage changes in capital and output, respectively.<sup>6</sup>

The two ‘technical’ ratios (capital-labor and capital-output) are instrumental for the determination of labor productivity in the LC sub-model, which is then transmitted back to the PS sub-model. Potential output per worker = KL ratio / KO ratio, and the ‘technical’ label refers to the technology assumed embedded in the new capital acquisitions. New capital equipment is assumed to have enhanced engineering-based performance (KO ratio declines) and require less labor (KL increases). The equations in the appendix are not complicated, but they would not be intuitive to most students. Thus, extra effort is needed to explain the intuition while summarizing the formulation details and the theoretical underpinnings.

To prepare for the discussion of the Wage & Price sub-model, take another look at Figure 4, and note the two variables with similar names: ‘output per worker’ and ‘potential output per worker.’ The latter is the engineering concept discussed above; it reflects the productive potential when the capital equipment is in used by trained workers. The actual output per worker is an output to the Wage & Price submodel and is explained in the next section.

**Wage & Price Sub-Model.** Figure 5 displays *Lite’s* Wage & Price (WP) sub-model, a familiar reinforcing feedback loop connecting wages and prices (with equations in the appendix).

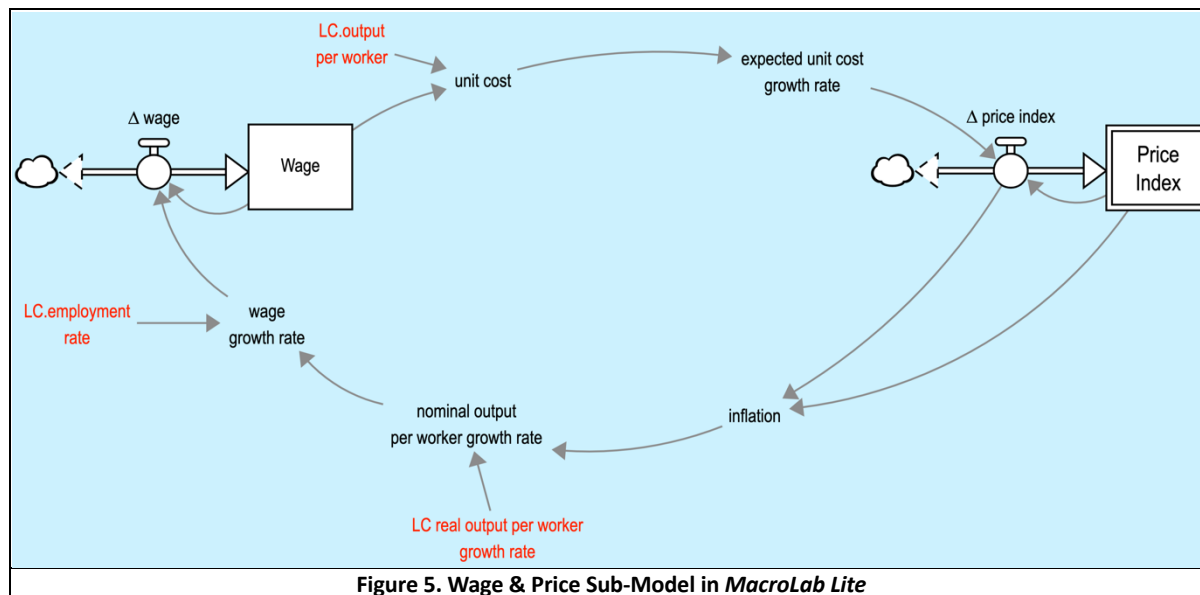


Figure 5. Wage & Price Sub-Model in *MacroLab Lite*

The triggers for wage & price feedback loop come from the Labor & Capital sub-model (itself activated by real AD). Displayed in Figure 4, ‘LC. output per worker’ is a sales concept that is endogenously dependent on the labor stock and real AD. It is a simple calculation that all managers can do: divide sales by the number of workers to determine the average sales per

<sup>6</sup> Indeed, an alternative identity-inspired behavioral hypothesis is that labor = output / output per worker. It, too, has a non-tautological interpretation when output per worker is conceptualized and modeled from an engineering perspective and is not endogenously dependent on the value of the labor stock.

worker. The wage hypothesis illustrated in Figure 5 reflects the view that managers can easily justify the use of ‘sales per worker’ as a measure of productivity for determining wages and as the denominator in a unit labor cost calculation.

In the U.S. data for 1990-2018, the wage growth rate is proportional to the growth rate of nominal output (i.e., sales: aggregate demand) per worker; i.e., the real growth rate plus inflation. However, the wage growth rate is slightly lower than the nominal output growth rate. The complete wage hypothesis, therefore, includes a labor market effect. The wage growth rate is also a function of the employment rate, which is usually in the mid-90 percent range. The tighter the labor market, the closer the employment rate moves toward 100%. In the wage growth rate equation, therefore, the nominal output per worker growth is multiplied by the employment decimal fraction. Importantly, a wage growth rate moderated by the labor market effect tends to reduce a tendency towards a runaway wage-price spiral; in SD terms, it weakens the positive feedback loop.

The price hypothesis is that prices consist of unit costs and a percentage markup. That hypothesis is captured by making the growth rate of prices a function of the growth rate of unit costs. The average markup is already present in current prices and it, too, grows by the same percentage. Finally, the Price Index is an output to the Production & Sales sub-model, where it closes an essential supply side negative feedback loop and converts nominal AD to real AD.

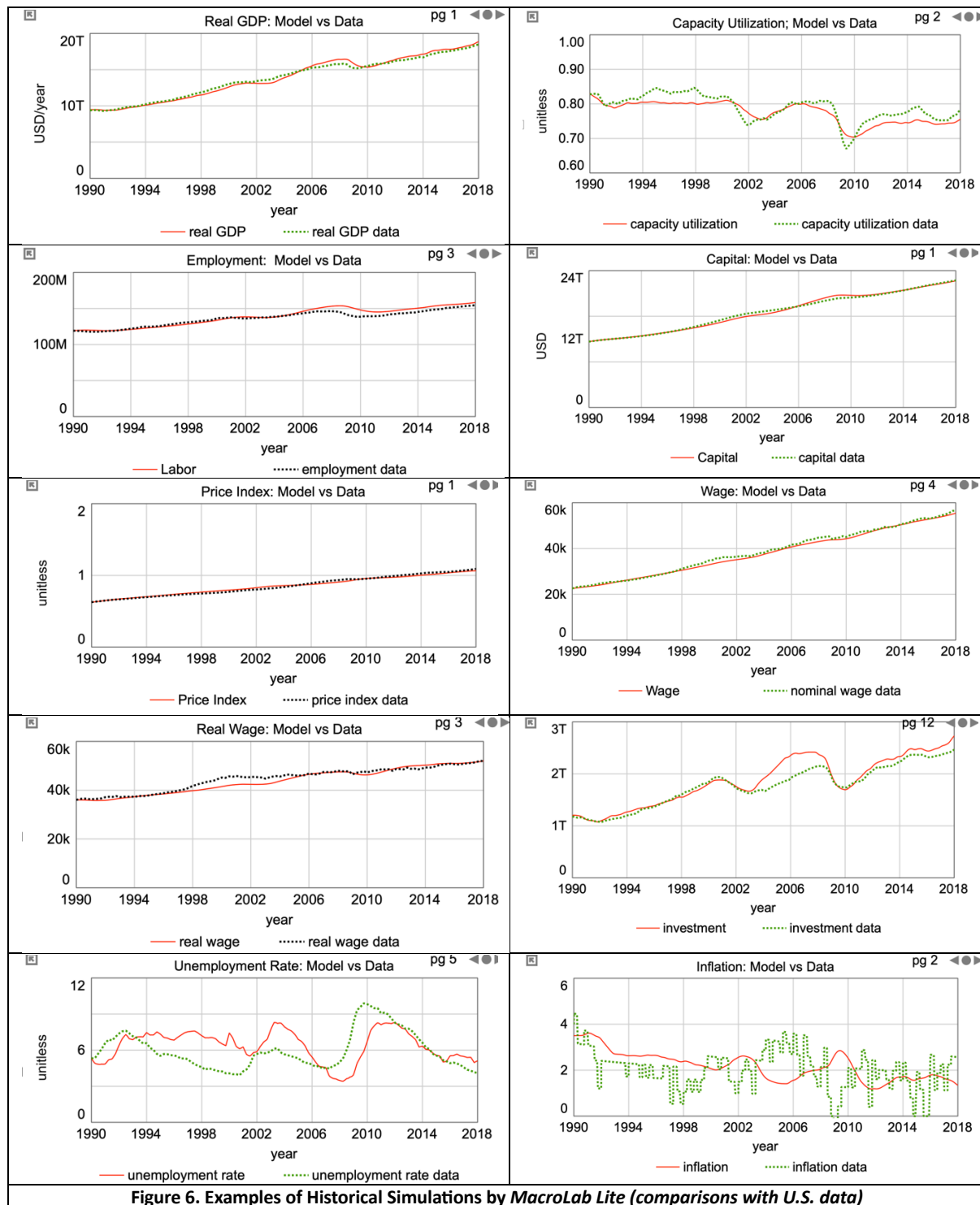
### **Simulating Historical Behavior**

*MacroLab Lite* has two modes of simulation: experimental and historical. The experimental mode initializes the model in equilibrium and permits exogenous shock tests during simulation runs, thereby aiming to build intuition about the relationship between the model’s structure and its post-shock behavior. In contrast, the historical mode initializes the model with U.S. data, simulates an empirical model economy, and permits comparison with the performance of the U.S. economy since 1990. Each mode makes a separate contribution to student learning of macroeconomics; student access to both should reinforce the benefits of each.

This final section illustrates *Lite*’s historical mode. The behavior of the calibrated supply side of the model is compared with the performance of the U.S. economy between 1990 and 2018.<sup>7</sup> When the historical mode switch is ON, stocks and parameters are initialized with historical values of U.S. data. In the absence of a Demand Side, time series data for nominal aggregate demand is an input to the Production and Sales sub-model. The endogenous structure of the Supply Side responds to the exogenous demand shock and the sub-models function as described. On the next page, Figure 6 displays eight comparisons with historical data: GDP, capacity utilization, employment, capital, price index, nominal wage, real wage, unemployment rate, and inflation. Readers can make their own assessment of how well the supply side of this simple model transformed the exogenous demand time series into a set of macroeconomic indicators.

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<sup>7</sup> As explained in the introduction, the Demand Side of *MacroLab Lite* is still in design stage. It should be ready for discussion at the conference.



This short paper has illustrated the design principles for the Supply Side structure of *MacroLab Lite*, a simplified teaching model for introductory macroeconomics. The Demand Sides structure should be completed in time for discussion at the conference. Comments are welcome from economics researchers, economics instructors, and economics students.



## References

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## Appendix: Supply Side Sub-Model Equations in *MacroLab Lite*

### Production & Sales Sub-Model

$Inventories(t) = Inventories(t - dt) + (real\ GDP - real\ AD) * dt$	USD
$real\ AD = FF.nominal\ AD / WP.Price\ Index$	USD/year
$real\ AD\ growth\ rate = 100 * TREND(real\ AD, .25)$	per year
$real\ GDP = LC.production\ capacity * desired\ capacity\ utilization$	USD/year
$desired\ capacity\ utilization = desired\ output / LC.production\ capacity$	unitless
$desired\ inventory\ adjustment = (.14 * SMTH1(real\ AD, .25) - Inventories) / 1.0$	USD/year
$desired\ output = SMTH1(real\ AD, .25) + desired\ inventory\ adjustment$	USD/year

### Labor & Capital Sub-Model

$Capital(t) = Capital(t - dt) + (investment - depreciation) * dt$	USD
$Labor(t) = Labor(t - dt) + (net\_hiring) * dt$	persons
$depreciation = Capital / avg\ life\ of\ capital$	USD/year
$investment = Capital * desired\ capital\ growth\ rate / 100$	USD/year
$net\ hiring = Labor * labor\ growth\_rate / 100$	person/year
$avg\ life\ of\ capital = 10$	years
$capital\ growth\ rate = 100 * TREND(Capital, DT, .03)$	per year
$depreciation\ rate = 100 * (depreciation / Capital)$	per year
$desired\ capital\ growth\ rate = SMTH1(PS.real\ AD\ growth\ rate, 2) + depreciation\ rate$	per year
$KL\ ratio\ growth\ rate = 100 * TREND(technical\ KL\ ratio, DT)$	per year
$labor\ growth\ rate = capital\ growth\ rate - KL\ ratio\ growth\ rate$	per year
$output\ per\ worker = PS.real\ AD / Labor$	USD/year/person
$potential\ output\ per\ worker = technical\ KL\ ratio / technical\ KO\ ratio$	USD/year/person
$production\ capacity = Labor * potential\ output\ per\ worker$	USD/year
$technical\ KL\ ratio = 97000 * ((Capital / INIT(Capital))^{.475}) / SMTH1(CU / init(CU), 2)$	USD/person
$technical\ KO\ ratio = average\ KO\ ratio * capacity\ utilization\ data\ trend$	years

### Wage & Price Sub-Model

$Price\ Index(t) = Price\ Index(t - dt) + (\Delta\ price\ index) * dt$	unitless
$Wage(t) = Wage(t - dt) + (\Delta\ wage) * dt$	USD/year
$\Delta\ price\ index = Price\ Index * expected\ unit\ cost\ growth\ rate / 100$	per year
$\Delta\_wage = (Wage * (wage\ growth\ rate) / 100)$	USD/year/year
$Expected\ unit\ cost\ growth\ rate = 100 * TREND(unit\_cost, 2.5)$	per year
$inflation = 100 * (\Delta\ price\ index / Price\ Index)$	per year
$nominal\ output\ per\ worker\ growth\ rate = real\ output\ per\ worker\ growth\ rate + inflation$	per year
$real\ output\ per\ worker\ growth\ rate = 100 * TREND(output\ per\ worker, .25)$	per year
$unit\ cost = Wage / LC.output\ per\ worker$	USD/year/person
$wage\ growth\ rate = .95 * nominal\ output\ per\ worker\ growth\ rate$	per year

Note the embedded numerical values in ‘desired inventory adjustment.’ It illustrates a simplification technique used for a few other variables in *MacroLab Lite*. Experience suggests that, once students understand that constant numbers can be used inside equations, they prefer looking at one variable with a less intuitive equation if that means there will be fewer variables in the diagram.

For desired inventory adjustment, for example, we can omit parameters for inventory coverage, smoothing time, and inventory adjustment time by strategic placement of .14, .25, and 1.0 (each measured in years). One drawback to this simplification is that the software has no way to confirm that the equation’s units are correct, and a ‘units error’ message appears at the bottom of the screen. This is disconcerting after so much emphasis has been placed on getting the units right when students are introduced to modeling. But they can write the equation with the three explicit parameters and confirm that the units are correct before simplifying.