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FPL–PELPS
A Price Endogenous Linear Programming System for Economic Modeling, Supplement to PELPS III, Version 1.1

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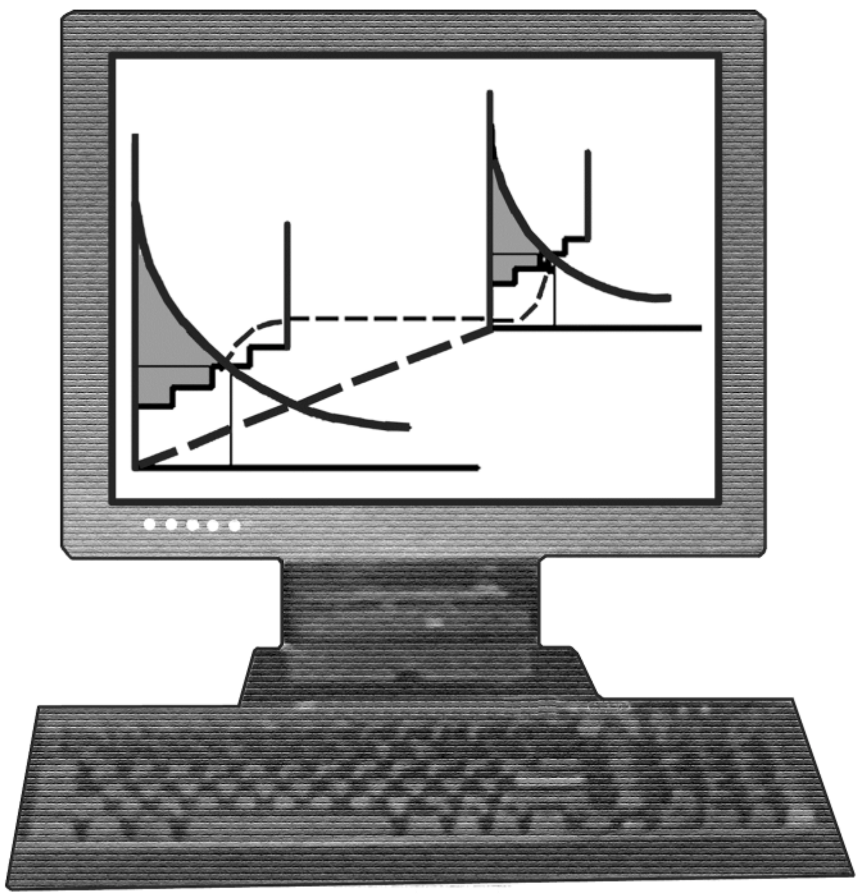

Abstract

This report provides documentation and user information for FPL–PELPS, a personal computer price endogenous linear programming system for economic modeling. Originally developed to model the North American pulp and paper industry, FPL–PELPS follows its predecessors in allowing the modeling of any appropriate sector to predict consumption, production and capacity by technology, and trade within or among several regions or countries. The theoretical structure is that of spatial equilibrium modeling under competitive market assumptions. This report contains a mathematical description of the system, including its extensions from previous versions, and a detailed user's guide with an application of FPL–PELPS.

Keywords: economic model, linear programming, spatial equilibrium, international trade, price, demand, supply, capacity, technology, recycling, industry, pulp and paper, solid wood

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A Price Endogenous Linear Programming System for Economic Modeling, Supplement to PELPS III, Version 1.1

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Introduction

Overview of FPL–PELPS

The Forest Products Laboratory version of the Price Endogenous Linear Programming System (FPL–PELPS) is a general personal computer system that allows for extensive modeling of economic sectors. FPL-PELPS is a successor to several systems that provide its primary theoretical and mechanistic base: PELPS (Gilless and Buongiorno 1985), PELPS II (Calmels and others 1989), PELPS II PLUS (Zhang and others 1990), PELPS III Version 1.0 (Zhang and others 1993), and PELPS III Version 1.1 (Zhang and others 1995). The impetus for the version published here is the ability to handle certain resource and technological issues characteristic of forest product economic sectors analyzed by the USDA Forest Service.[1]

As in all previous versions of PELPS, FPL–PELPS has a static phase that solves a spatial equilibrium problem cast as a price endogenous linear program. It is capable of computing a multi-region, multi-commodity economic equilibrium by determining the quantities and prices that clear all markets at a given point in time and that satisfy material balance, capacity, and technological constraints and allow the maximization of the sum of producer and consumer surplus, minus relevant costs, for each region. FPL–PELPS also has a dynamic phase that uses recursive programming techniques to obtain a multi-period dynamic solution that predicts the evolution of the spatial equilibrium over time.

Although the history of the PELPS programs is tied to the modeling of specific forest product sectors, such as pulp and paper and solid wood, the system is very general. With the appropriate data it can be applied to many other economic sectors.

[1]Another version, PELPS IV, was developed in conjunction with the Global Forest Products Model (GFPM) (Buongiorno and others 2003).

Document Outline

This document provides the economic justification and mathematical model on which FPL–PELPS is based. Following the mathematical formulation, details on the installation and execution of the program in Microsoft Windows 95 are given in the context of a workable example. The system has been adapted to other personal computer configurations than those outlined, such as more recent operating systems, but this may require some software setting adjustments and/or recompilations of the code to work properly.

Changes From PELPS III

Changes have been incorporated into FPL–PELPS since the release of PELPS III Version 1.0, several of which were described in an unpublished report (PELPS III Version 1.1 by Zhang and others 1995). The most significant changes are as follow:

1. The ability to specify by-products that are generated during the manufacture of a primary product.
2. The ability to specify an overtime capacity as a fraction of regular capacity.
3. The ability to constrain more than two recycled subcommodities from an aggregate commodity.
4. The ability to extend the capacity change model based on Tobin's *q* theory (Tobin 1969) to accommodate longer lags between price stimulus and investment response and growth rate changes based on the maturity of the industry.
5. The ability to specify raw material supply that is adjusted for natural growth and drain, thus influencing future availability of supply.

6. The move to more recent Microsoft Windows environments (Windows 95 and later), which allows the adaptability of the system to operate with different versions of Lotus 1-2-3 as well as other spreadsheet packages. This may, however, require macro or other programming on the part of the user to ensure that the data files conform to the input formats described in the Appendix.

Historical Perspective

The Forest and Rangeland Renewable Resources Planning Act (RPA) of 1974 requires the USDA Forest Service to periodically assess the long-term supply and demand of forest resources by projecting the competitive market balance between supply, demand, and prices for forest resources. The information gathered in the assessments is used by the Administration and Congress to make informed management and policy decisions. Forest resource assessments have a long history, but the RPA formalized the process to ensure the reliability of the information while maintaining enough flexibility to allow improvements and modifications to the framework, including societal, ecological, and long-term implications. Further information on the RPA, including its current status and history, can be found in the most recent release, *2000 RPA Assessment of Forest and Range Lands* (USDA Forest Service 2001), and electronically at www.fs.fed.us (keyword search: RPA).

The assessment provides data and documentation for planners to address a multitude of resource issues, including timber assessments composed of solid wood and wood fiber economic sector evaluations. Beginning in the early 1980s, the Timber Assessment Market Model (TAMM, Adam and Haynes 1980) was used in making equilibrium price projections for the solid softwood sector. The economic importance of the North American pulp and paper sector was recognized and development proceeded on a model known as PAPYRUS (Buongiorno and Gilless 1983, Gilless and Buongiorno 1987). The PAPYRUS model was one of the first applications of a general computerized economic model known as the price endogenous linear programming system (PELPS), also developed by Gilless and Buongiorno (1985). These efforts were supported by the USDA Forest Service, Forest Products Laboratory (FPL), and development over the years led to the PELPS successors, including PELPS II (Calmels and others 1989), PELPS II PLUS (Zhang and others 1990), PELPS III (Zhang and others 1993), and PELPS III V1.1 (Zhang and others 1995). Several iterations of PELPS III have been developed in support of the FPL Pulpwood Model (Ince and others 1987, Howard and others 1988), the North American Pulp and Paper Model (NAPAP, Ince and others 1993, Zhang and others 1996), and the North American Solid Wood Sector Model (NASAW, Phelps 1998). Further RPA projections with the NAPAP and NASAW models culminated in FPL–PELPS.

The modeling framework of the 5th RPA Timber Assessment combines the TAMM and NAPAP economic models in an iterative approach with the timber inventory model, ATLAS, and with the land-use, forest-type change model, AREACHANGE. Further details can be found in Haynes (2002 and 2003), Haynes and Skog (2002), Adams (2002a,b), Ince and Durbak (2002), Alig and others (2002), as well as on the USDA Forest Service, Pacific Northwest Research Station website (www.fs.fed.us/pnw).

Static Phase

Samuelson (1952) described a spatial equilibrium model as one for which

> …we are given at each of two or more localities a domestic demand and supply curve for a given product (e.g. wheat) in terms of its market price at that locality. We are also given constant transport costs (shipping, insurance, duties, etc.) for carrying one unit of the product between any two of the specified localities.

and from which we desire to know the final competitive equilibrium of prices in all the markets, of amounts supplied and demanded at each place, and of exports and imports.

Thus, spatial equilibrium models attempt to simulate interregional economies by finding the balance of demand, supply, and trade that will result in competitive market equilibrium among the regions. Samuelson (1952) mathematically modeled these types of markets using a linear programming formulation qualitatively described by Enke (1951). Cast as a linear program, the market equilibrium is found as the quantities and prices that clear the markets while maximizing the sum of consumer and producer surplus for each region in a sector adjusted for transportation costs. This sum is referred to as the “net social payoff” of the sector; McCarl and Spreen (1980) provide interpretation and justification. The linear programming formulation of the spatial equilibrium problem was developed by Duloy and Norton (1975).

FPL–PELPS initially solves a generalized version of the classical spatial equilibrium model of Samuelson (1952) for a specified base period. The generalization allows formal modeling of production, transportation, transformation, and consumption of many commodities within and between multiple regions. A commodity may be a primary raw material (such as pulpwood), a recovered material (such as wastepaper), a consumed commodity (such as newsprint), or a secondary commodity that is the result of the production of another commodity (a by-product or co-product). An example of the latter is an engineered wood product constructed from chip residues from lumber production. Consumed commodities may be described as virgin commodities (made only of new raw material, such as virgin pulp), recycled commodities (made of recovered materials, such as recycled paper), and intermediate commodities. Consumer wastes may enter the recycle stream, whereas producer wastes may be considered by-products if there is sufficient demand for them as a secondary commodity or as part of a secondary commodity.

FPL–PELPS contains demand, supply, and manufacturing regions. The demand (supply) of a commodity in a region is described by an equation that gives quantity demanded (supplied) as a function of price. The demand for recycled commodities is constrained by recycling policies, whereas the supply of recycled commodities is also constrained by the amount of materials available. The production of commodities occurs in manufacturing regions, with the manufacturing processes (activities) represented in the model by activity analysis (Takayama and Judge 1971). Each manufacturing process has a limited capacity. Within a process, a commodity can be made with different combinations of the inputs, referred to as input mixes. The combination of manufacturing coefficients, giving the amount of each input needed to produce a unit of output, and the associated unit manufacturing cost define the input mix.

The shipment of commodities between the various regions is modeled explicitly with a transportation cost consisting of a per-unit freight cost and appropriate import and export ad-valorem taxes.

FPL–PELPS explicitly recognizes exchange rates for regions, making international models possible.

Dynamic Phase

In the dynamic phase of FPL–PELPS, a multi-period spatial equilibrium problem is broken down into a sequence of "static" problems, one for each period in the forecast, similar to the "recursive programming" approach of Day (1973), which simulates partial long-run optimizing behavior. Each static problem gives an equilibrium solution relative to the demand, supply, and capacity constraints and associated costs in that period. The constraints and associated costs are updated in each period to reflect both exogenous and endogenous changes. Exogenous changes can include shifts in demand related to population and income growth, shifts in supply related to inventory growth or interest rate fluctuations, and changes in costs, taxes, and exchange rates. Production capacity changes can be modeled endogenously based on one of two prevailing theories, the acceleration principle of Clark (1917) or the *q* theory of Tobin (1969). Both theories are basically functions of the capacity's shadow price in the previous period, the cost of increasing capacity, and past capacity (for the *q* theory model) or past production (for the acceleration model).

Mathematical Formulation

FPL–PELPS has two modeling elements: a static phase that models the state of the sector at a given point in time and a dynamic phase that models the transition of the sector from the previous state to the next state over a specified period of time, such as from year to year.

Static Phase

The static phase finds the market equilibrium of the sector by maximizing net social surplus subject to material balance, manufacturing capacity, recycling constraints, and by-product restrictions. The net social surplus is expressed as a linear approximating function of the sum of producer and consumer surplus in all regions of the sector, and the constraints within the sector are modeled by linear inequalities. The market equilibrium can then be found as the solution to this linear program (LP).

Objective Function

Following Samuelson (1952) and Takayama and Judge (1971), the sum of producer and consumer surplus is given by the area under all the demand curves up to the quantities demanded minus the area under all the supply curves up to the quantities supplied, minus the sum of net manufacturing costs and minus the net transportation costs. That is, the general objective function can be expressed as

$$\text{Max} \quad Z = Z_{\text{d}} - Z_{\text{s}} - Z_{\text{m}} - Z_{\text{t}} \tag{1}$$

where

$$Z_{\text{d}} = \sum_k \sum_i \int_0^{D_{ik}} P_{ik}(D_{ik})dD_{ik}$$

is the area under the demand curves,

$$Z_{\text{s}} = \sum_k \sum_j \int_0^{S_{jk}} P_{jk}(S_{jk})dS_{jk}$$

is the area under the supply curves,

$$Z_{\text{m}} = \sum_j \sum_k \sum_p \sum_x m_{jkpx} Y_{jkpx}$$

is the sum of net manufacturing costs, and

$$Z_{\text{t}} = \sum_k \sum_i \sum_j d_{ijk} T_{ijk}$$

is the sum of net transportation costs,

and in which D, S, Y, and T are quantities demanded, supplied, manufactured, and transported, P is a price expressed in common currency, d and m are unit costs expressed in common currency, i and j are regions (demand and supply, respectively), k is a commodity, p is a process, and x is an input mix (technically feasible combination of inputs needed to produce one unit of commodity k, using process p).

FPL–PELPS uses a stepwise approximation of the demand and supply curves so that the spatial equilibrium can be computed efficiently by linear programming. Based on linear approximations of the area under the demand curves (Z_{d}) and the area under the supply curves (Z_{s}), the objective function value is easily approximated. Stepwise approximation is done in a similar manner for both demand and supply curves as explained in the following text.

Demand Equation

The demand equation for commodity k in region i for the base period is defined by an initial demand quantity (D_{ik}^0), demand price (P_{ik}^0), and elasticity (σ_{ik}) of price with respect to quantity. The short-run demand curve (for the base period) is defined by the following:

$$\frac{D_{ik}}{D_{ik}^0} = \left(\frac{P_{ik}}{P_{ik}^0}\right)^{\sigma_{ik}} \text{ if } \sigma_{ik} \neq \infty \text{ (that is, nonlinear demand)}$$

or

$$P_{ik} = P_{ik}^0 \text{ if } \sigma_{ik} = \infty \text{ (that is, horizontal demand)}$$

The demand equations can be constrained such that at least a certain quantity of a commodity in a region is demanded by specifying a nonzero lower bound (D_{ik}^{L}) on the demand curves:

$$D_{ik} \geq D_{ik}^{\mathrm{L}}$$

Stepwise Approximation of Demand Curve

A linear approximation to each demand curve is developed in order to approximate the area beneath all demand curves (Z_{d}) in the objective function. Omitting subscripts for region and commodity (i, k), each demand curve is defined in the price and quantity dimension by its own demand equation, as follows:

$$P(D) = P^0 \left(\frac{D}{D^0}\right)^{1/\sigma} \tag{2}$$

In the base period, P^0 and D^0 are the initially specified demand price and demand quantity for each commodity and region and σ represents the elasticity of demand with respect to price. The smooth curve in Figure 1 is an example of Equation (2). The figure also provides a simplified illustration of how the stepwise approximation of a demand curve is created using D^0, P^0, and σ.

First, based on a user-defined operating (run-time) parameter, two endpoints of an interval on the quantity axis are determined that will enclose the range for the stepwise approximation to the demand curve. The user-specified value, r, is a number between 0 and 1 that indicates the solution range in which the new equilibrium demand quantity (D^*) is expected to be found. The endpoints of the interval are defined by the values $D_{\min}$ and $D_{\max}$ as follows:

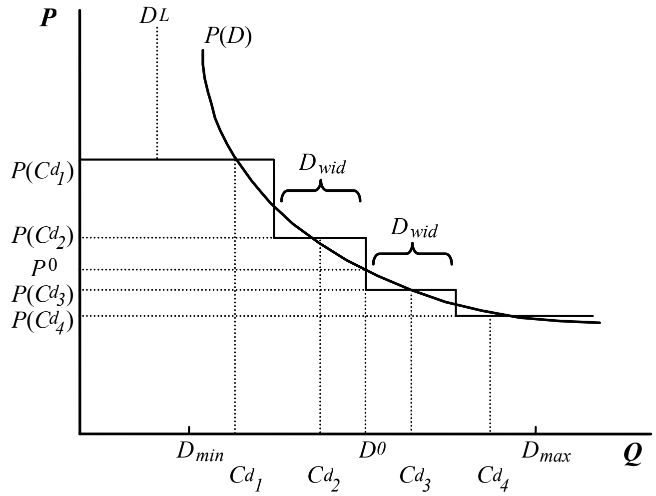

Figure 1—Stepwise approximation of nonlinear demand curve in FPL–PELPS. D^{L} is an optional parameter that is model dependent.

$$D_{\min} = D^0(1-\mathrm{r})$$

$$D_{\max} = D^0(1+\mathrm{r})$$

Specifying a narrow interval (i.e., a small r) will increase precision of the stepwise approximation, but the interval should generally be large enough so that it will encompass the magnitude of possible changes in equilibrium demand quantities from one period to the next in a given scenario. (Note that the same r value applies to supply curves as well, as discussed below, so that r should generally be large enough to encompass period changes in equilibrium supply quantities as well).

After the interval has been delineated, a series of steps are defined within it. The width of each step inside the interval (D_{wid}) is a function of the length of interval and the number of steps, h, which is another user-specified operating parameter:

$$D_{\mathrm{wid}} = \frac{D_{\max} - D_{\min}}{h}$$

Increasing the number of steps, h, will increase the precision of the stepwise approximation, but this can also significantly increase the size of linear program if there are a large number of demand (and/or supply) equations.

Since the steps within the interval will be centered over the demand curve defined by Equation (2), it is necessary to calculate a series of price coefficients and quantity bounds to include in the linear program. The demand quantity at the center of the j-th step inside the interval is defined as

$$C_j^d = D_{\min} + \frac{D_{\mathrm{wid}}(2j-1)}{2}$$

The price associated with the demand quantity at the j-th step C_j^d is then calculated as

$$P(C_j^d) = P_0 \left(\frac{C_j^d}{Q_0} \right)^{1/\sigma}$$

The stepwise approximation to the demand curve is completed by extending price at the first step to the left (to zero quantity) and by extending price at the last step to the right without a constraint on quantity. Following the example in Figure 1, D_j is defined as the model demand quantity that is associated with each price ($P(C_j^d)$). Thus, the approximated area under the demand curve is

$$\sum_{j=1}^{h} D_j P(C_j^d)$$

with the model demand quantities on each step constrained as

$$D_1 \le D_{\min} + D_{\text{wid}}$$

and

$$D_j \le D_{\text{wid}} \quad \text{for } j = 2 \text{ to } h-1$$

The demand quantity for the last step (D_h) is unconstrained. The equilibrium demand quantity D^* is then calculated after the LP is solved as

$$D^* = \sum_{j=1}^{h} D_j$$

In addition, aggregate equilibrium demand may be constrained by a specified lower bound as

$$\sum_{j=1}^{h} D_j \ge D^{\text{L}}$$

Notice that demand prices are not solution variables of the primal linear program. The equilibrium price for each commodity within a demand region is obtained as the shadow price of the material balance constraint of the corresponding region and commodity. The shadow price of the material balance constraint equates to marginal cost (in the dual linear program), and short-run profit maximizing behavior in competitive markets is defined as price equals marginal cost at equilibrium. Further details can be found in Hazell and Norton (1986) and Schrage (1997).

Supply Equation

The supply equation of commodity k in region j for the base period is defined by an initial supply quantity (S_{jk}^0), demand price (P_{jk}^0), and elasticity (λ_{jk}) of price with respect to quantity. The short-run supply curve (for the base period) is defined by the following:

$$\frac{S_{jk}}{S_{jk}^0} = \left(\frac{P_{jk}}{P_{jk}^0} \right)^{\lambda_{jk}} \quad \text{if } \lambda_{jk} \ne \infty \text{ (that is, nonlinear supply)}$$

or

$$P_{jk} = P_{jk}^0 \quad \text{if } \lambda_{jk} = \infty \text{ (that is, horizontal supply)}$$

A supply equation can be constrained not to exceed a certain quantity of a commodity in a region by specifying a nonzero upper bound (S_{jk}^{U}) on the supply curve:

$$S_{jk} \le S_{jk}^{\text{U}}$$

Stepwise Approximation of Supply Curve

Similar to the linear approximation for a demand curve, a linear approximation to each supply curve is developed to approximate the area beneath all supply curves (Z_s) in the objective function. Omitting subscripts for region and commodity (j, k), each supply curve is defined in the price and quantity dimension by its own supply equation, as follows:

$$P(S) = P^0 \left(\frac{S}{S^0} \right)^{1/\lambda} \qquad (3)$$

In the base period, P^0 and S^0 are the initially specified supply price and supply quantity for each commodity and region and λ represents the elasticity of supply with respect to price. The smooth curve in Figure 2 is an example of Equation (3).

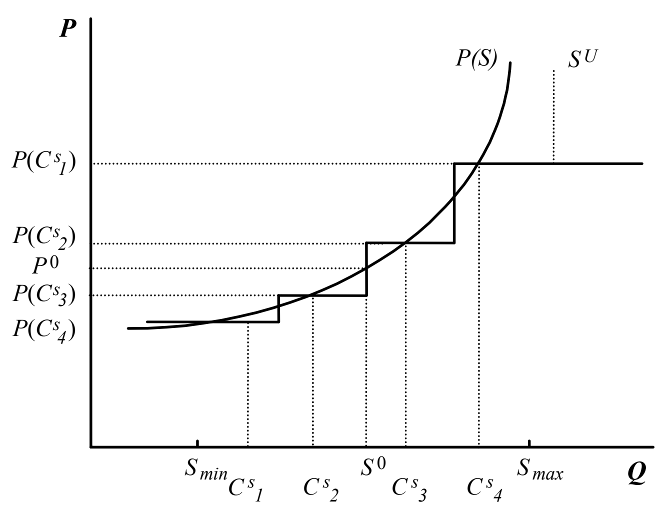

Figure 2—Stepwise approximation of nonlinear supply curve in FPL–PELPS. S^L (not shown) and S^U are optional parameters that are model dependent.

The figure also provides a simplified illustration of how the stepwise approximation of a supply curve is created using S^0, P^0, and λ.

Again, as in demand, based on a user-defined operating (run-time) parameter, two endpoints of an interval on the supply axis are determined that will enclose the range for the stepwise approximation to the supply curve. The same user-specified value, r, indicates the solution range in which the new equilibrium supply quantity (S^*) is expected to be found. The endpoints of the interval are defined by the values $S_{\min}$ and $S_{\max}$ as follows:

$$S_{\min} = S^0 \left(1 - r\right)$$

$$S_{\max} = S^0 \left(1 + r\right)$$

Refer to the section on stepwise approximation of a demand curve for further discussion of the precision parameter, r. Note that since the same r value applies to all supply and demand curves, judicious choice of r is required to allow for the magnitude of periodic changes in equilibrium supply and demand quantities.

After the interval has been delineated, a series of steps are defined within it. The width of each step inside the interval (S_{wid}) is a function of the total length of the interval and the number of steps, h, which is also a user-specified operating parameter as described earlier:

$$S_{\text{wid}} = \frac{S_{\max} - S_{\min}}{h}$$

Increasing the number of steps, h, will increase the precision of the stepwise approximation, but this can also significantly increase the size of the linear program if there are large numbers of demand and/or supply equations.

Since the steps within the interval will be centered over the supply curve defined by Equation (3), it is necessary to calculate a series of price coefficients and quantity bounds to include in the linear program. The supply quantity at the center of the i-th step inside the interval is defined as

$$C_i^s = S_{\min} + \frac{S_{\text{wid}}(2i - 1)}{2}$$

The associated price for the supply quantity at the i-th step C_i^s is then calculated as

$$P(C_i^s) = P_0 \left(\frac{C_i^s}{Q_0} \right)^{1/\lambda}$$

The stepwise approximation to the supply curve is completed by extending price at the first step to the left (to zero quantity) and by extending price at the last step to the right without constraint. Following the example in Figure 2, S_i is defined as the model supply quantity that is associated with each price ($P(C_i^s)$). Thus, the approximated area under the supply curve is

$$\sum_{i=1}^{h} S_i P(C_i^s)$$

with the model supply quantities on each step constrained as

$$S_1 \le S_{\min} + S_{\text{wid}}$$

and

$$S_i \le S_{\text{wid}} \;\text{ for } i = 2 \text{ to } h - 1$$

The supply quantity for the last step (S_h) is unconstrained. The equilibrium supply quantity S^* is then calculated after the LP is solved as

$$S^* = \sum_{i=1}^{h} S_i$$

In addition, aggregate equilibrium supply may be constrained by a specified upper bound S^{U} as

$$\sum_{i=1}^{h} S_i \le S^{\text{U}}$$

and simultaneously constrained by a specified lower bound S^{L} by

$$\sum_{i=1}^{h} S_i \ge S^{\text{L}}$$

Notice that supply prices, like demand prices, are not solution variables of the primal linear program. The equilibrium price for each commodity within a supply region is obtained as the shadow price of the material balance constraint of the corresponding region and commodity. The shadow price of the material balance constraint equates to marginal cost (in the dual linear program) and short-run profit maximizing behavior in competitive markets is defined as price equals marginal cost at equilibrium. Further details can be found in Hazell and Norton (1986) and Schrage (1997).

Material Balancing Constraints and Prices

Within each demand, supply and manufacturing region, the inflow of a commodity must balance with the outflow. This is satisfied by specifying that the amount of a commodity supplied, manufactured, and transported into a region must be greater than or equal to the quantity demanded, used in manufacturing of other commodities in the same region, and transported out of the region:

$$S_{jk} + \sum_p \sum_x Y_{jkpx} + \sum_i T_{ijk} - D_{jk} - \sum_n \sum_q \sum_y a_{jknqy} Y_{jnqy} - \sum_i T_{jik} \geq 0 \text{ for all } j,k \quad (4)$$

where the manufacturing coefficient a_{jknqy} is the amount of input commodity k needed to manufacture a unit of output commodity n, in region j, by process q, using input mix y. If a commodity k has a minimum recycled content requirement, then for sub-commodity l the material balance constraint is specified to be

$$S_{jl} + \sum_p \sum_x Y_{jlpx} + \sum_i T_{ijl} - D_{jkl} - \sum_n \sum_q \sum_y a_{jlnqy} Y_{jnqy} - \sum_i T_{jil} \geq 0 \text{ for all } j,l$$

while the material balance for the aggregate commodity k is

$$S_{jk} + \sum_p \sum_x Y_{jkpx} + \sum_i T_{ijk} - (D_{jk} + \sum_l D_{jkl}) - \sum_n \sum_q \sum_y a_{jknqy} Y_{jnqy} - \sum_i T_{jik} \geq 0 \text{ for } j,k$$

Typically, the aggregate commodity will not be supplied, manufactured, or transported as are the sub-commodities, reducing the last material balance constraint to contain only the demand variables. Also, in this situation, the aggregate commodity is further constrained by a recycling requirement (see following text).

The manufacturing cost of a primary commodity in a region j is the sum of the cost of transforming input into product and the regional shipping cost. The objective function coefficient m_j is the manufacturing cost, as expressed in the common currency, in region j of one unit of primary commodity k by process p and mix x.

In addition, careful consideration of by-products is necessary and appropriate manufacturing processes and cost coefficients should be added to the model to account for their production.

By-Product Constraints

The production of a primary commodity will often result in the production of a secondary commodity (by-product or co-product) that has substantial value in the marketplace. The amount of by-product generated, Y_{jbnpx}, is constrained to be a proportion b_{jbnpx} of the primary product Y_{jnpx}:

$$b_{jbnpx} Y_{jnpx} - Y_{jbnpx} = 0 \quad (5)$$

where the subscript j represents region of production, b is the by-product, n is the primary commodity, p is the process, and x is the input mix. The economical impact of the production of by-products must be considered; they may be viewed as offering a reduction in manufacturing costs.

Manufacturing Capacity Constraints

In each region, the production of a commodity by a process is limited by the existing manufacturing capacity of that process. That is,

$$\sum Y_{jkpx} \leq K_{jkp} \quad \text{for all } j, k, \text{ and } p$$

where K_{jkp} is the capacity of process p and x is an input mix. The shadow price π_{jkp} of this constraint is the value of one additional unit of capacity to make commodity k in region j by process p.

Overtime Manufacturing Capacity Constraints

Short-term (i.e., within-period) increases in production capacity of a commodity by a process within a region may be simulated by extending working hours or adding a shift or shifts at an increased cost. The short-run or temporary increase in capacity, K^{o}_{jkp}, is defined in FPL–PELPS as "overtime capacity" and is expressed as a proportion, α_{jkp}, of regular capacity:

$$K^{o}_{jkp} = \alpha_{jkp} K_{jkp}$$

where K_{jkp} is the regular capacity for the production of commodity k in region j by process p.

Recycling Constraints

Two types of recycling constraints can be simulated with FPL–PELPS: one imposed on demand curves and the other imposed on supply curves, representing minimum recycled content and recovered waste restrictions, respectively. If a minimum recycled content restriction is imposed on a commodity, the commodity must be split into sub-commodities, one for each manufacturing process, where a process represents an alternative level of the recycled material in the manufacture of the commodity. For example, a demanded commodity, k, which can be produced by three processes, can be considered as three sub-commodities. The aggregate commodity and sub-commodities can then be constrained by

$$\sum_l \alpha_{ikl} D_{ikl} - \alpha_{ik} D_{ik} \geq 0 \quad \text{for appropriate } i, k$$

where α_{ik} is the desired minimum fraction of recycled content in commodity k in region i and α_{ikl} is the fraction of recycled content in sub-commodity l. The specification of the manufacture of the sub-commodity will have an associated process mix x, but the mix is implicit in the recycling demand restriction.

If a recovered waste restriction is imposed on a commodity, an upper and/or lower bound may be applied to the supply of recovered waste to reflect maximum and/or minimum recovery rates, respectively. If S_{jr} is the quantity of commodity r that is to be recovered in region j, then

$$S_{jr}^{\mathrm{L}} \le S_{jr} \le S_{jr}^{\mathrm{U}}$$

where S_{jr}^{L} and S_{jr}^{U} are lower and upper bounds, respectively, on the supply of recycled commodity r in region j.

Resource Drain

Supply commodities may be drawn from an aggregate resource whose net growth may need to be monitored because changes may possibly influence future supplies. Net growth can be modeled as outlined in FPL–PELPS dynamic modeling capabilities. The growth and use of such resources in the base period is defined as

$$I_{jl} = \alpha_{jl}\left(I_{jl0} - \sum_{k} \beta_{jkl} S_{jkl} \right)$$

where I_{jl0} is the inventory of resource l in region j in the period prior to the base period, α_{jl} is the growth coefficient for the resource, S_{jkl} is the amount of commodity k supplied from resource l in region j for the base period, and β_{jkl} is the fraction of the supply commodity drawn from the resource. This calculation has no influence on the base period model solution.

General Example

Following the PELPS III manual, the simple example will be expanded to illustrate the conceptual static model that FPL–PELPS is designed to capture. Assume that there are three regions: supply, manufacturing, and demand (Fig. 3). A commodity is produced in the supply region by a process summarized by a supply curve. This commodity is transported to the manufacturing region, where the manufacturing technology that transforms this commodity into a consumable commodity A is described by an input-output coefficient (amount of input required per unit of output) and by the unit cost of manufacturing (net of input cost). This primary commodity A is consumed in the demand region, which is defined by a demand curve. The production of commodity A results in the additional production of by-product B as a specified percentage of the production of A. By-product B is then transformed into a secondary commodity C by a different technological process. Also, assume constant transportation costs for carrying one unit of product between the supply and manufacturing regions, one unit of primary product A between the manufacturing region and the demand region, and one unit of secondary product C between the manufacturing region and the demand region.

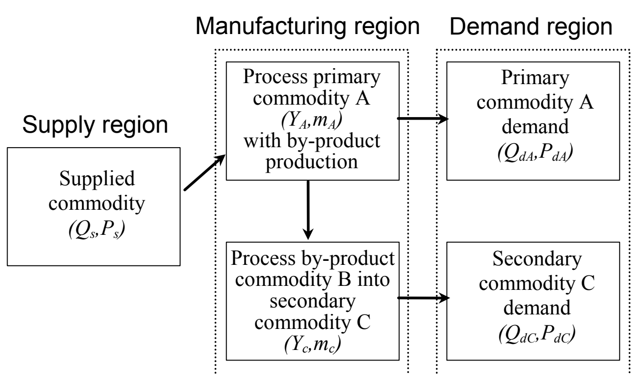

Figure 3—Simple general FPL–PELPS example illustrating by-products.

The final competitive equilibrium for this problem can be found, as stated previously, by maximizing the sum of the producer and consumer surplus in all three regions, subject to the appropriate material balancing constraints in each region and the manufacturing capacities available.

Define

Q_s, P_s	quantity and price of supplied commodity S
Q_A, P_A	quantity and price of demanded commodity A
Q_C, P_C	quantity and price of demanded commodity C
Y_A, Y_C	quantity of commodities A and C manufactured
Y_B	quantity of by-product B produced
m_A, m_C	manufacturing costs associated with production of commodities A and C
b_A	amount of by-product B produced per unit of manufactured commodity A
T_S, T_A, T_C	quantity transported between regions
d_s, d_A, d_C	cost of transporting one unit of commodities S, A, and C
a_A, a_C	amount of input commodity per unit of output commodity A and C
K_A, K_C	manufacturing capacity of commodities A and C

The competitive equilibrium is found by solving the following optimization problem:

$$\text{Max} \int_0^{Q_A} P_A(Q_A)dQ_A + \int_0^{Q_C} P_C(Q_C)dQ_C - \int_0^{Q_S} P_S(Q_S)dQ_S - m_A Y_A - m_C Y_C - d_S T_S - d_A T_A - d_C T_C$$

subject to the supply, production, and demand constraints for primary commodity *A*,

$$Q_S - T_S \geq 0$$

$$T_S - a_A Y_A \geq 0$$

$$Y_A - T_A \geq 0$$

$$T_A - Q_A \geq 0$$

$$Y_A \leq K_A$$

and the production and demand constraints for secondary commodity *C*,

$$b_A Y_A - Y_B = 0$$

$$Y_B - a_C Y_C \geq 0$$

$$Y_C - T_C \geq 0$$

$$T_C - Q_C \geq 0$$

$$Y_C \leq K_C$$

If the associated dual variables are represented by π_i, $i = 1$ to 10 corresponding to the order of these constraints, then the Kuhn–Tucker conditions (i.e., dual constraints and complementary slackness conditions) are given by the following:

$$\pi_1 = P_S$$

$$\pi_2 = \pi_1 + d_S$$

$$\pi_4 = P_A = \pi_3 + d_A$$

$$\pi_3 = m_A + a_A \pi_2 - b_A \pi_6 + \pi_5$$

$$\pi_7 = \pi_6$$

$$\pi_8 = m_C + a_C \pi_7 + \pi_{10}$$

$$\pi_9 = P_C = \pi_8 + d_C$$

$$\pi_5 (Y_A - K_A) = 0$$

$$\pi_{10} (Y_C - K_C) = 0$$

The solution that satisfies both the primal and dual constraints and complementary slackness conditions will be the "optimal" solution in that it will maximize net social surplus as given by the objective function. The shadow price or "scarcity premium" for an increase in production of primary commodity *A* is given by π_5 and an increase in production of commodity *C* is given by π_{10}. If the production capacity level is not met, then that associated shadow price (π_5 or π_{10}) is necessarily zero to satisfy the complementary slackness conditions. Note that the demand commodity prices can be expressed as functions of the appropriate transportation costs, manufacturing costs, supply costs, and scarcity premiums. Alternatively, if the secondary commodity *C* produced using the by-product as input is not constrained, then the opportunity cost for the production of the primary product *A* is the demand price for product *A* plus adjusted demand price for the secondary commodity *C* minus manufacturing and supply costs for product *A* and adjusted manufacturing and supply costs for product *C*. The price and cost adjustments for the secondary commodity *C* are to express prices and costs on a per unit basis of product *A*.

If the production of the secondary commodity *C* is at its constrained capacity, care must be taken in the interpretation of the model results since the commodity can be a controlling economic factor and it may need to be modeled as a primary commodity.

Summary Tableau

Table 1 gives an example of a general representation of an FPL–PELPS static model, expressed in tableau form, as would be solved by a linear program. Not all the features of FPL–PELPS are included in this example.

Dynamic Phase

Defining the transition from one period to the next to model exogenous and endogenous economic changes constitutes the dynamic phase of FPL–PELPS. The changes that can be modeled include shifts in demand and supply; changes in exchange rates, costs and other parameters; and changes in manufacturing capacity.

Demand

The demand equation of commodity *k* in demand region *i* for period *t* is as follows:

$$D_{ik,t} = (e_{i,t} P_{ik,t})^{\sigma_{ik,t}} X_{1ik,t}^{\delta_{ik}} X_{2ik,t}^{\tau_{ik}} X_{3ik,t}^{\alpha_{ik}} D_{ik,t-1}^{\eta}$$
$$= P_{ik,t}^{\sigma_{ik,t}} e_{ik,t}^{\sigma_{ik,t}} X_{1ik,t}^{\delta_{ik}} X_{2ik,t}^{\tau_{ik}} X_{3ik,t}^{\alpha_{ik}} D_{ik,t-1}^{\eta}$$

where *e* is the monetary exchange rate with respect to the common currency in demand region *i* (this term is needed to ensure that values in the objective function are expressed in common units of measure; *e* is 1.0 for region(s) operating with common currency), σ is elasticity of demand with respect to price, X_1, X_2, and X_3 are exogenous shifters of demand over time, δ, τ, and α are elasticities with respect to change in exogenous shifters over time, and η is a partial adjustment coefficient. Different exogenous shifters of demand, different elasticities, and different partial adjustment parameters can be utilized for different commodities and demand regions. In addition to exogenous changes in demand shifters, the price elasticity of demand (σ) for each commodity and the exchange rate (*e*) can be changed over time.

Table 1—Summary tableau

	Variable				
	Demand	Supply	Manufacturing	Transportation	
Objective function:					
Maximize	$\sum_i \sum_k \sum_n P(D_{ikn}) D_{ikn}$	$-\sum_j \sum_k \sum_n P(S_{jkn}) S_{jkn}$	$-\sum_j \sum_k \sum_p \sum_x m_{jkpx} Y_{jkpx}$	$-\sum_i \sum_j \sum_k d_{ijk} T_{ijk}$	
Subject to:					RHS
Demand constraints					
Step size	D_{ik1} (for all i,k)				$\leq D_{ik}^{\min} + D_{ik}^{\mathrm{wid}}$
	D_{ikn} (for $n = 2,\ldots,h-1$, and all i,k)				$\leq D_{ik}^{\mathrm{wid}}$
Lower bound	$\sum_{n=1} D_{ikn}$				$\geq D_{ik}^{\mathrm{L}}$
Supply constraints					
Step size		S_{jk1} (for all j,k)			$\leq S_{jk}^{\min} + S_{jk}^{\mathrm{wid}}$
		S_{jkn} (for $n = 2,\ldots,h-1$, and all j,k)			$\leq S_{jk}^{\mathrm{wid}}$
Lower bound		$\sum_{n=1} S_{ikn}$			$\geq S_{jk}^{\mathrm{L}}$
Upper bound		$\sum_{n=1} S_{ikn}$			$\leq S_{jk}^{\mathrm{U}}$
Material balance constraints	$-D_{jk}$	$+S_{jk}$	$+\sum_p \sum_x Y_{jkpx} - \sum_n \sum_q \sum_y a_{jknqy} Y_{jnqy}$	$+\sum_i T_{ijk} - \sum_i T_{jik}$	≤ 0
Capacity constraints			$\sum_x Y_{jkpx}$		$\leq K_{jkp}$
By-product constraints			$b_{jbnpx} Y_{jnpx} - Y_{jbnpx}$ (for all by-products)		$=0$

When (D^0,P^0) is defined as a point on the demand curve in period t, the short-run demand curve for that period is defined by the following:

$$\frac{D_{ik,t}}{D_{ik,t}^0} = \left(\frac{P_{ik,t}}{P_{ik,t}^0} \right)^{\sigma_{ik,t}} \qquad \text{if } \sigma \neq \infty \text{ (that is, nonlinear demand)}$$

or

$$P_{ik,t} = P_{ik,t}^0 \qquad \text{if } \sigma = \infty \text{ (that is, horizontal demand)}$$

The demand equations can be constrained such that a minimum quantity of a commodity in a region is demanded by specifying a nonzero lower bound ($D_{ik,t}^{\mathrm{L}}$) on the demand curves:

$$D_{ik,t} \geq D_{ik,t}^{\mathrm{L}}$$

As for the static phase, a linear approximation to each demand curve in period t is developed to facilitate an approximation of the area beneath all demand curves (Z_{d}) in the objective function (Z) for that period. Omitting subscripts for region and commodity (i, k), each demand curve for period t is defined in the price and quantity dimension as shown in the static phase (Eq. (2)), except that now P^0 is P^*_{t-1}, the competitive equilibrium demand price from the previous period. The quantity that would be demanded in the current period at this price is computed as the new D^0:

$$D^0 = D_{t-1}^* \left(1 + \frac{\Delta X_{1,t}}{X_{1,t-1}} \right)^{\delta} \left(1 + \frac{\Delta X_{2,t}}{X_{2,t-1}} \right)^{\tau} \left(1 + \frac{\Delta X_{3,t}}{X_{3,t-1}} \right)^{\alpha} \times \left(1 + \frac{\Delta e_t}{e_{t-1}} \right)^{\sigma} \left(\frac{D_{t-1}^*}{D_{t-2}^*} \right)^{\eta} \qquad (6)$$

where Δ refers to the exogenous change between the two periods (i.e., $\Delta V_t = V_t - V_{t-1}$) for designated shifter variables (X_d, d = 1, 2, 3) and exchange rate (e), and D^*_{t-1} and D^*_{t-2} are the equilibrium demand quantities from the previous two periods. Note that shifter variable X_d is exogenously specified in the system as its associated rate of change, $\Delta X_{dt} / X_{d,t-1}$.

If demand is perfectly elastic (i.e., $\sigma = \infty$), then the shift for demand follows

$$P^0 = P_{t-1}^* \left(1 + \frac{\Delta X_{1,t}}{X_{1,t-1}} \right)^{\delta} \left(1 + \frac{\Delta X_{2,t}}{X_{2,t-1}} \right)^{\tau} \left(1 + \frac{\Delta X_{3,t}}{X_{3,t-1}} \right)^{\alpha}$$

If a lower bound has been specified, the new lower bound is determined by

$$D^{\mathrm{L}} = D_{t-1}^{\mathrm{L}} \left(1 + \frac{\Delta D_t^{\mathrm{L}}}{D_{t-1}^{\mathrm{L}}} \right)$$

where ΔD^{L}_t is the specified exogenous change in the bound for period t. The system requires the input of $\Delta D_t^{\mathrm{L}} / D_{t-1}^{\mathrm{L}}$.

Supply

The supply equation of commodity k in supply region j for period t is the following:

$$S_{jk,t} = (e_{j,t} P_{jk,t})^{\lambda_{jk,t}} X_{1jk,t}^{\rho_{jk}} X_{2jk,t}^{\mu_{jk}} X_{3jk,t}^{\phi_{jk}} I_{jk,t-1}^{\psi_{jk}} S_{jk,t-1}^{\xi}$$

$$= P_{jk,t}^{\lambda_{jk,t}} e_{jk,t}^{\lambda_{jk,t}} X_{1jk,t}^{\rho_{jk}} X_{2jk,t}^{\mu_{jk}} X_{3jk,t}^{\phi_{jk}} I_{jk,t-1}^{\psi_{jk}} S_{jk,t-1}^{\xi}$$

where e is the monetary exchange rate with respect to the common currency in supply region j (this term is needed to ensure that values in the objective function are expressed in common units of measure; e is 1.0 for region(s) operating with common currency), λ is elasticity of supply with respect to price, X_1, X_2, and X_3 are exogenous shifters of supply over time, ρ, μ, and ϕ are elasticities with respect to exogenous shifters, I is resource inventory at start of period, ψ is elasticity of supply with respect to resource stock, and ξ is a partial adjustment coefficient. Different exogenous shifters of supply, different elasticities, and different partial adjustment parameters can be utilized for different commodities and supply regions. In addition to exogenous change in supply shifters, the price elasticity of supply (λ), the resource stock elasticity (ψ) for each commodity, and the exchange rate (e) can be shifted exogenously over time.

When (S^0, P^0) is defined as a point on the supply curve in period t, the short-run supply curve for that period is defined by the following:

$$\frac{S_{jk,t}}{S_{jk,t}^0} = \left(\frac{P_{jk,t}}{P_{jk,t}^0} \right)^{\lambda_{jk,t}} \quad \text{if } \lambda \neq \infty \text{ (that is, nonlinear supply)}$$

or

$$P_{jk,t} = P_{jk,t}^0 \quad \text{if } \lambda = \infty \text{ (that is, horizontal supply)}$$

Supply can be constrained such that the amount of a commodity supplied in a region falls within certain bounds by specifying nonzero lower and upper bounds ($S_{jk,t}^{\mathrm{L}}$, $S_{jk,t}^{\mathrm{U}}$) on the supply curves:

$$S_{jk,t}^{\mathrm{L}} \leq S_{jk,t} \leq S_{jk,t}^{\mathrm{U}}$$

As for the static phase, a linear approximation to each supply curve in period t is developed to facilitate an approximation of the area beneath all supply curves (Z_{s}) in the objective function (Z) for that period. Omitting subscripts for region and commodity (j, k), each supply curve for period t is defined in the price and quantity dimension as shown in the static phase (Eq. (3)), except that now P^0 is P^*_{t-1}, the competitive equilibrium supply price from the previous period. The quantity that would be supplied in the current period at this price is computed as the new S^0:

$$S^0 = S^*_{t-1}\left(1+\frac{\Delta X_{1,t}}{X_{1,t-1}}\right)^{\rho}\left(1+\frac{\Delta X_{2,t}}{X_{2,t-1}}\right)^{\mu}\left(1+\frac{\Delta X_{3,t}}{X_{3,t-1}}\right)^{\phi} \times\left(1+\frac{\Delta I_t}{I_{t-1}}\right)^{\psi}\left(1+\frac{\Delta e_t}{e_{t-1}}\right)^{\lambda}\left(\frac{S^*_{t-1}}{S^*_{t-2}}\right)^{\xi} \quad (7)$$

where Δ refers to the exogenous change between the two periods for designated shifter variables (X_s, s=1, 2, 3) and exchange rate (e), and S^*_{t-1} and S^*_{t-2} are the equilibrium supply quantities from the previous two periods. Changes to the resource (e.g., timber) inventory are estimated endogenously. Note that shifter variable X_s is exogenously specified in the system as its associated rate of change, $\Delta X_{st}/X_{s,t-1}$.

If supply is perfectly elastic (i.e., $\lambda = \infty$), then the shift for supply follows

$$P^0 = P^*_{t-1}\left(1+\frac{\Delta X_{1,t}}{X_{1,t-1}}\right)^{\rho}\left(1+\frac{\Delta X_{2,t}}{X_{2,t-1}}\right)^{\mu}\left(1+\frac{\Delta X_{3,t}}{X_{3,t-1}}\right)^{\phi}$$

If an upper bound has been specified, the bound can be exogenously adjusted by

$$S^{\mathrm{U}} = S^{\mathrm{U}}_{t-1}\left(1+\frac{\Delta S^{\mathrm{U}}_t}{S^{\mathrm{U}}_{t-1}}\right)$$

where ΔS^{U}_t is the specified exogenous change in the bound for period t. This is exogenously specified to the system as $\Delta S^{\mathrm{U}}_t / S^{\mathrm{U}}_{t-1}$.

Exchange Rates

All prices and costs in FPL–PELPS are expressed in a common currency. Hence, any change in the value of a region's currency influences prices and costs as expressed in the common currency. The exchange rate is updated as

$$e_{i,t} = e_{i,t-1} + \Delta e_i$$

where $e_{i,t}$ is the exchange rate of region i at time t and Δe_i refers to the exogenous change between two consecutive periods. The change in exchange rate affects manufacturing costs, costs of new capacity, and transportation costs. Changes also shift demand and supply as outlined in the previous text.

Manufacturing and By-Product Coefficients

A manufacturing coefficient (a_{jknqy}) is specified for each process and input mix in the material balancing constraint (Eq. (4)). This coefficient defines the amount of an input commodity k needed to manufacture one unit of output commodity n using a particular process q and input mix y in the region j. For multi-period forecasts to capture technical progress within certain manufacturing processes, this coefficient can be updated exogenously.

Similarly, the proportion of a secondary commodity (by-product) generated from the production of a primary commodity may change over time, and the coefficient (b_{jbnpx}) for the by-product constraint (Eq. (5)) can be updated exogenously.

Manufacturing Cost

Manufacturing costs can change from both changes in production costs (in real domestic prices) and changes in the exchange rate of the associated region. Changes in net manufacturing costs can be specified exogenously and will automatically be updated for changes in regional exchange rates as

$$m_{jkpx,t} = m_{jkpx,t-1}\left(1+\frac{\Delta m^{\mathrm{d}}_{jkpx,t}}{m^{\mathrm{d}}_{jkpx,t-1}}\right)\left(\frac{e_{j,t-1}}{e_{j,t}}\right)$$

where $m^{\mathrm{d}}_{jkpx,t-1}$ is the previous period's cost in domestic currency (i.e., $e_{j,t-1} \cdot m_{jkpx,t-1}$) and Δ refers to the exogenous change in real manufacturing cost in domestic currency between two consecutive periods. Note that what is input exogenously to the system is the rate of change, $\Delta m^{\mathrm{d}}_t / m^{\mathrm{d}}_{t-1}$.

Manufacturing Capacity

Capacity changes from one period to the next can be either imposed exogenously or computed endogenously. Endogenous changes may either follow a q or an accelerator model of capacity change.

***q* Model—**Changes in capacity computed endogenously using the q model are based on Tobin's q theory of capital investment (Tobin 1969). This theory of capital investment behavior suggests "the rate of investment—the speed at which investors wish to increase capital stock—should be related, if to anything, to q, the value of capital relative to its replacement cost" (Tobin 1969). Following Tobin's q theory, the change in capacity for each manufacturing process is specified as an increasing function of the q ratio, the value of current capacity (π) relative to the cost of new capacity (c). The simple q model of capacity expansion has been successful for modeling the mature phases of the pulp and paper sectors (Ince 1994, 1999; Ince and Durbak 2002; Zhang and Buongiorno 1993), but less successful for modeling emerging market sectors, such as particleboard, Southern Pine plywood, and oriented strandboard (Spelter 1995). To extend the capabilities of the FPL–PELPS modeling system, a more general implementation was adopted to capture differing effects of the *q* ratio over various phases of an industry's life cycle. In addition to allowing for greater time for lagged effects, start-up effects are allowed that are commonly associated with smaller capacities. As capacities increase, as in a more mature market, the start-up effects decline asymptotically reflecting the more typical *q* behavior.

In FPL–PELPS, for each manufacturing process, the gross change in capacity is determined by the following *q* model:

$$\Delta K^{\mathrm{g}}_{jkpt} = K_{jkpt}\left(b_{00jkp} + \sum_{i=1}^{5}\left(b_{1ijkp}q_{jkp,t-i+1} + b_{2ijkp}\frac{q_{jkp,t-i+1}}{K_{jkp,t-i}}\right) + b_{33jkp}\frac{\Delta K^{\mathrm{g}}_{jkp,t-1}}{K_{jkp,t-1}}\right) \quad (8)$$

where K^{g}_{jkpt} is gross production capacity of commodity *k* by process *p* in region *j* at beginning of period *t*, $q_{jkp,t-i}$ is *q* ratio defined as shadow price of capacity divided by cost of new capacity based on lag *i*, and multiple *b* represent expansion parameters as specified by the user.

The net change in capacity for process *p* in region *j* at time *t* is then calculated as

$$\Delta K^{\mathrm{n}}_{jkpt} = \Delta K^{\mathrm{g}}_{jkpt} - \Delta K^{\mathrm{d}}_{jkpt}$$

where $\Delta K^{\mathrm{d}}_{jkpt}$ is the change in capacity resulting from depreciation (i.e., $r_{jkp}K_{jkpt}$). Thus, the constraining capacity level at the beginning of the next period is

$$K_{jkp,t+1} = K_{jkpt} + \Delta K^{\mathrm{n}}_{jkpt}$$

Exogenous adjustments are allowed for capacity level, capacity depreciation rate, capacity cost, and expansion parameters.

In addition, any overtime process capacities are adjusted based on exogenous specifications of the ratio of overtime capacity to regular capacity and the newly calculated process capacity.

Accelerator Model—The accelerator model of capacity expansion follows previous PELPS versions as outlined in Zhang and others (1993). This model is based on the acceleration principle of Clark (1917) that suggests investment spending is determined by changes in production levels. Although programming has been updated for this model in FPL–PELPS, it is unsupported at this time. However, a variant of this type of model has been adopted for modeling regional forestry sectors and the global forestry sector by the Food and Agriculture Organization (FAO) of the United Nations. Mathematical details and a software user's guide for the Global Forest Products Model (GFPM) can be found in Tomberlin and others (1999).

Transportation Cost

Transportation costs are updated to include specified changes in freight costs and ad-valorem taxes by

$$d_{ijk,t} = f_{ijk,t-1}\left(1 + \frac{\Delta f_{ijk,t}}{f_{ijk,t-1}}\right)\left(\frac{e_{i,t-1}}{e_{i,t}}\right) + P_{ik,t-1}\left(x^{\mathrm{e}}_{ik,t-1} + \Delta x^{\mathrm{e}}_{ik,t}\right) + \left(P_{ik,t-1} + d_{ijk,t-1}\right)\left(x^{\mathrm{i}}_{jk,t-1} + \Delta x^{\mathrm{i}}_{jk,t}\right)$$

where $f_{ijk,t-1}$ is freight cost for shipping commodity *k* from region *i* to region *j* in previous period, $\Delta f_{ijk,t}$ refers to exogenous change in freight cost (in common currency) between two periods, $x^{\mathrm{e}}_{ik,t-1}$ is export ad-valorem tax rate in region *i* on commodity *k* in previous period, $\Delta x^{\mathrm{e}}_{ik,t}$ is change in export ad-valorem tax rate from previous period, $x^{\mathrm{i}}_{jk,t-1}$ is import ad-valorem tax rate in region *j* on commodity *k* in previous period, $\Delta x^{\mathrm{i}}_{jk,t}$ is change in import ad-valorem tax rate from previous period, $P_{ik,t-1}$ is price of commodity *k* in region *i* in previous period, and $d_{ijk,t-1}$ is cost in previous period for transporting commodity *k* from region *i* to region *j*. Note that for the previous period, the price of commodity *k* in region *j*, $P_{jk,t-1}$, is equal to $P_{ik,t-1} + d_{ijk,t-1}$. The freight cost exogenous specification for the system is the rate of change, $\Delta f_t / f_{t-1}$.

Minimum Recycled Content

The minimum recycled content for a consumed commodity can be updated exogenously by adjusting the minimum percent content for the aggregate commodity or minimum percent recycled content for each associated sub-commodity. The exogenous specification to the system consists of the newly updated coefficients.

Recovery Constraints for Recycling

Minimum and maximum waste recovery rates as well as the fraction of consumption of the associated commodity can be updated exogenously to adjust for changes in recovery of wastes and consumption characteristics. Combined with past consumption, the newly adjusted lower and upper bounds on the supply of recycled commodity in region *j* are calculated as

$$S^{\mathrm{L}}_{jr} = \sum_k w^{-}_{jkr}\left(\alpha_{jk}\sum_i D_{ik,t-1}\right)$$

$$S^{\mathrm{U}}_{jr} = \sum_k w^{+}_{jkr}\left(\alpha_{jk}\sum_i D_{ik,t-1}\right)$$

where w^{-}_{jkr} and w^{+}_{jkr} are minimum and maximum recovery rates of commodity *r* recovered as waste from consumed commodity k in region j, respectively; α_{jk} is fraction of total consumption of commodity k in supply region j; and $D_{ik,t-1}$ is consumption of commodity k in region i in previous period.

Resource Growth and Drain

Supply commodities may be drawn from an aggregate resource whose net growth could possibly influence future supplies. The growth and use of such resources is monitored by the following growth–drain model:

$$I_{jl,t} = \alpha_{jl}\left(I_{jl,t-1} - \sum_{k} \beta_{jkl} S_{jkl,t-1} \right)$$

where $I_{jl,t}$ is inventory of resource l in region j at time t, $I_{jl,t-1}$ is inventory in previous period, α_{jl} is the growth coefficient for the resource in region j, $S_{jkl,t-1}$ is amount of commodity k supplied from this resource in region j in previous period, and β_{jkl} is percentage of supplied commodity withdrawn from the resource. Exogenous changes in the growth and drain coefficients are made to the system by specifying the updated coefficients.

User's Guide

Installing FPL–PELPS

FPL–PELPS is a menu-driven system that runs as a console application in a DOS window under Microsoft Windows 95, an official personal computer operating system of the USDA Forest Service. This system has primarily been used in conjunction with Lotus 1-2-3 for Windows; however, other spreadsheet packages that can output the required data in the proper format can be used (see Appendix for data file specifications).

Hardware and Software Requirements

The minimum requirements for FPL–PELPS for Windows 95 are the following:

- A personal computer system with at least 2 megabytes of free space on the C: drive and a pentium (or newer) class of processor. This space requirement is only for executable files. Worksheet and data files will require additional space that will depend on the size of the model.
- Microsoft Windows 95 (FPL–PELPS has operated under more recent versions of Windows; however, operation on these operating systems cannot be guaranteed).
- Lotus 123 for Windows release 4.0 or later.
- HYPER LINDO/PC. LINDO, a trademark of Lindo Systems Inc. (Schrage 1997). (The command for recent LINDO versions has changed and now requires either a modified FPL–PELPS menu program or an alias command.)

Installation

1. The FPL–PELPS programs must reside in the TPELPS1 folder on the C: drive to operate correctly. To install the FPL–PELPS files on the C: drive:
2. Open Windows Explorer. Since the programs are required to run under a C:/Tpelps1 subdirectory, if you currently have a folder named Tpelps1, it must be renamed.
3. Select the floppy drive that contains the diskette with the FPL–PELPS executable files. The right-hand window of Windows Explorer should contain the Tpelps1 folder.
4. Drag the Tpelps.1 folder to the left-hand window of the Windows Explorer window so that it is positioned over the C: drive. (The C: drive label will be highlighted when correctly positioned.)
5. Close Windows Explorer.
6. If desired, create a shortcut to FPL–PELPS so that it can be launched from the desktop:
   - Left click on Start menu, left click on Settings, left click on Taskbar. In the window that appears, left click on Start Menu Programs tab. Then click Advanced. An Explorer window will appear, which contains the links and shortcuts for the Programs area and other areas of the Start menu. You will need to find a shortcut for MS-DOS prompt—this may be under Accessories (click on Programs, then Accessories) or some other folder, or it may be under the main programs. Left click on MS-DOS prompt then right click and drag to the icon to where you would like it on the desktop. Release the mouse button. A menu should appear. Click on "Create shortcut here," then close the Explorer window (through File, Close or double-click on left corner) and the taskbar window (click on Cancel button).
   - Right click on the newly created icon (it should have the words MS-DOS on it) and a menu should appear. Left click on Properties so that a properties window appears. Left click on Program tab and make the following changes:
     - Change title to read "FPL–PELPS" or "TPELPS1" or some other identifiable label. This label will appear on the DOS window when opened.
     - Change "working:" directory to "C:\TPELPS1"
     - Change "batch file:" to "C:\TPELPS1\TPELP1PA.BAT". Make sure that this batch file sets up your path correctly, changes the directory to C:\TPELPS1\PELPS, then executes the appropriate batch file to start the programs (C:\TPELPS1\PELPS\FPLPELPS.BAT

or C:\TPELPS1\PELPS\PELPSIV.BAT). An example of the contents could be:

PATH=C:\;C:\WINDOWS;C:\WINDOWS\COMMAND;C:\LINDO;C:\TPELPS1;C:\TPELPS1\PELPS
CD C:\TPELPS1\PELPS
FPLPELPS

– Change “Run:” to Normal (click on down arrow to show options)
– Click “Change Icon.” A window with icon options will appear. Choose a suitable icon to represent the program. Click OK
– Click OK in the properties window

To rename the icon, right click on it again. Left click on Rename, delete “MS-DOS Prompt,” and type in desired name, such as FPL–PELPS.

Properties associated with the launching of FPL–PELPS in Windows 95 may need to be modified. If necessary, this can be done by right-clicking on the shortcut created and choosing Properties from the menu. This will display the associated DOS-mode property sheets.

Alternatively, you can manually create the necessary directory (C:\TPELPS1) and subdirectory (C:\TPELPS1\PELPS) and copy the FPL–PELPS files from the disk to their appropriate subdirectory.

There is a README.TXT file on the distribution disks that contains file listings, brief file descriptors, data file formats, and other important installation/run-time information.

FPL–PELPS can be removed through the Microsoft Explorer window by highlighting the TPELPS1 subdirectory and deleting through the File menu option.

Running FPL–PELPS

As an example suppose a sector model follows the static example given previously, except that specific values are now associated with the coefficients. The following text outlines the steps from data entry to final solution. The FPL–PELPS system, like its predecessors, relies on the user entering the necessary coefficients into spreadsheets that are subsequently saved to formatted data files. The system will then read these coefficients from the data files and write the formulated linear program (LP) to another data file in standard Mathematical Programming System (MPS) format. Details on MPS can be found in Murtagh (1981). LINDO will then read the LP from the MPS file and attempt to find a solution. FPL–PELPS invokes LINDO to execute with a LINDO script file that contains commands to read in the MPS data file, solve the LP, and direct solution output (both primal/dual) to various data files. FPL–PELPS interprets the LP solution and summarizes the solution in data files that can be viewed through a special Lotus 1-2-3 worksheet.

In a multi-period problem, FPL–PELPS cycles through LP evaluations and updates before control is returned to the user. Depending on several factors, including the size of the LP in each period, the number of periods, the extent of exogenous changes, and the speed of the computer, this process may be time consuming.

Starting FPL–PELPS

FPL–PELPS can be launched from the shortcut icon. Alternatively, FPL–PELPS can be started within a DOS window by changing directories to C:\TPELPS1, setting the path appropriately (a batch file similar to that described in the previous text can be used) and typing “FPLPELPS”. Whatever method you use to open FPL–PELPS, the following main menu should appear in the DOS window:

1) Edit or create input file
2) Define run-time parameters
3) Run base period
4) Run multi-periods—accelerator model
5) Run multi-periods—*q* model
6) Create output files
7) Quit FPL–PELPS

(If this window is full-screen, you will probably want to resize it with <ALT-ENTER>.)

Defining Control Parameters

Before solving a problem in FPL–PELPS, you will likely want to define the run-time parameters. To do this, choose option 2 (Define run-time parameters) from the FPL–PELPS main menu. You will be presented with a secondary menu with the following options:

1) Solution range
2) Number of steps
3) Length of projection
4) Return to main menu and save new options

The solution range defines the value *r* (see sections on Stepwise Approximation of a Demand Curve and Stepwise Approximation of a Supply Curve), which is used to calculate the range of quantities within which demand and supply equations will be approximated by linear steps. A value of 0.35, for example, means that the stepwise approximation will be done between 0.65 and 1.35 times the given equilibrium quantity for the base period or the previous equilibrium quantity for projection periods. Outside that range, demand and supply equations are horizontal up to any specified bounds as described previously. The default distributed with the installation disk is 0.35.

The number of steps defines the number of linear intervals used in the approximation of the demand and supply curves. A maximum of 26 steps can be specified, with a larger number corresponding to increased precision of the linearization process of the demand and supply curves about the equilibrium point. However, this increases the size of the linear program or programs and decreases the speed at which solutions are derived. The default distributed with the installation disk is 26 steps.

The length of projection defines the number of periods in a multi-period forecast. A single period is a fixed length of time that is relative to the specified economic problem. Commonly, a period is defined as 1 year; however, it can be any length of time as long as all data are consistent with the time unit. The default distributed with the installation disk is three periods.

Once these parameters are set to your satisfaction, you can return to the main menu by executing the last menu option.

Entering Data

Selection of the first main menu option (Edit or Create input file) results in the verification that input data files exist, followed by the text:

```
When finished saving data files

Press any key to continue...
```

At this point, if the FPL–PELPS window is full-screen, press <ALT-ESC> to minimize the window (do not close the window; FPL–PELPS should appear in the Windows 95 taskbar) or press <ALT-ENTER> to return to a DOS window, which can be minimized if desired.

FPL–PELPS has primarily been used with Lotus 1-2-3 and the distribution of the system includes an example worksheet (C:\TPELPS1\PELPS.WK4) that will be used to illustrate the system. For entry of new data, this worksheet is easily modified by cutting and pasting. However, for the worksheet macros to work correctly, column and row input must strictly adhere to those presented in the example. These macros will write the worksheet data into ASCII data files into the C:\TPELPS1 directory. The data files are subsequently used by the FPL–PELPS programs to create the linear program or programs associated with your model. The ASCII input data files can also be created in other ways, such as through alternate spreadsheet packages or a text editor. However, the input data files must follow the required format for the rest of the system to operate properly.

With FPL–PELPS waiting for the data files, launch Lotus 1-2-3 and read in the spreadsheet file C:\TPELPS1\PELPS.WK4. Within Lotus 1-2-3 make sure that the default working directory is set to C:\TPELPS1\PELPS, so that the macros will work correctly.

All prices and costs in FPL–PELPS must be expressed in a common currency (e.g., US$); any prices and costs that are in a domestic currency must be converted to the common currency and then entered into the worksheets. The exchange rates used for the base period conversions are entered into an Exchange Rate worksheet and can then be changed exogenously to reflect dynamic changes in real exchange rates for multi-period forecasts. FPL–PELPS will modify prices and costs accordingly.

Demand—The Demand worksheet (Worksheet A shown in Table 2) contains the coefficients that define each demand equation. The worksheet includes the following: a base demand quantity; corresponding unit base demand price expressed in a common currency (e.g., US$ per ton, per m^3, etc.), elasticity with respect to price, elasticities with respect to up to three shift variables, elasticity with respect to demand quantity of previous period, lower bound on demand quantity, and demand price and quantity of previous period. The price elasticity is the only elasticity necessary to calculate a static equilibrium. The other elasticities are used to adjust demand for multi-period projections, as described in Equation (6).

The region number and commodity number must be entered as alphanumeric characters for proper formatting in the data files. Values for other variables are entered as numeric and thus should contain zeroes (rather than blanks) if they are not to be used.

Several types of short-term demand curves can be modeled in FPL–PELPS as described previously in this document and also as described in the *PELPS III User's Guide* (Zhang and others 1993). Figure 1 shows an ideal nonlinear demand function, *P(D)*, described by Equation (2) and given by nonzero price, quantity, and price elasticity (P_0, D_0, σ) and zero lower bound on quantity demanded D. If a positive lower bound on the quantity demanded is given in the worksheet, then the ideal curve is similar to that illustrated in Figure 1, except there is a constraint on the minimum quantity demanded, D^L.

Table 2—Data for demand equations

A	A	B	C	D	E	F	G	H	I	J	K	L	M
1	******DEMAND******												
3	A: Region number (01 to 99, in ascending order)												
4	B: Commodity number (01 to 99, in ascending order)												
5	C: Base period price in common currency												
6	D: Base period quantity demanded at price C												
7	E: Price elasticity (<0, enter 0.00 for horizontal demand)												
8	F: Elasticity of demand with respect to the first shift variable (optional, enter 0.00 if omitted)												
9	G: Elasticity of demand with respect to the second shift variable (optional, enter 0.00 if omitted)												
10	H: Elasticity of demand with respect to the third shift variable (optional, enter 0.00 if omitted)												
11	I: Elasticity of demand with respect to previous-period demand (optional, enter 0.00 if omitted)												
12	J: Lower bound on the quantity demanded (optional, enter 0.00 if omitted)												
13	K: Quantity demanded in the period before the base period												
14	L: Price of commodity in the period before the base period												
15	M: Minimum fraction of recycled content												
16	reg	comm	price	quant	P elast	Shift1	Shift2	Shift3	Dem(-1)	Low bnd	Prv prc	Q(-1)	recyc
17	03	02	12.0	8.0	–1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	03	04	8.0	4.0	–1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	03	05	12.0	8.0	–1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.85
20													

Perfectly elastic demand curves (i.e., $\sigma = \infty$) can be indicated in the worksheet by entering a base period (reservation) price and setting the appropriate price elasticity to 0.00. This type of demand curve can be refined by specifying a lower bound on demand quantity, D^L. In dynamic projections, the shift variables can move horizontal demand curves up or down.

The example in Table 2 gives the necessary parameters for three demand curves. Line 17 describes the demand curve for commodity 02 in demand region 03; this demand curve is described with the base period quantity of 8.0 units at a price of 12.0 per unit (in common currency) and a price elasticity of –1.0. Elasticities of demand with respect to three shift variables are 0.0, 0.0, and 0.0. The elasticity with respect to previous-period demand is 0.0, and the lower bound on the quantity demanded is 0.0 units. Previous period price and quantity (before the base period) are left at 0.0 and 0.0, respectively.

Supply—The Supply worksheet (worksheet B, Table 3) contains the coefficients that define each supply equation. The worksheet includes the following: a base supply quantity, corresponding unit base supply price expressed in a common currency (e.g., US$ per ton, per m^3, etc.), elasticity with respect to price, elasticities with respect to up to three shift variables, elasticity with respect to supply quantity of previous period, elasticity with respect to resource stock from which commodity may be drawn, lower bound on supply quantity, upper bound on supply quantity, and supply price and quantity of previous period. The price elasticity is the only elasticity necessary to calculate a static equilibrium. The other elasticities are used to adjust supply for multi-period projections, as described in Equation (7). The numbers for region, commodity , and resource commodity (if used) must be entered as alphanumeric characters for proper formatting in the data files, whereas other variables are entered as numeric and thus should contain zeroes (rather than blanks) if they are not to be used. Resource commodity number '99' is reserved for special purposes and should not be used.

Several types of short-term supply curves can be defined in FPL–PELPS, as described previously and also as described in the *PELPS III User's Guide* (Zhang and others 1993). Figure 2 shows an ideal nonlinear supply function *P(S)* described by Equation (3) given by nonzero price, quantity, and elasticity (P_0, S_0, λ), zero lower bound on quantity supplied S^L, and unspecified upper bound S^U (zero is entered into the worksheet). If an upper bound on the quantity supplied is given in the worksheet, then the ideal curve is similar to that illustrated in Figure 2, except there is a constraint on the maximum quantity S^U. For the base period, upper and lower bounds must be provided for recovered wastes if they are to be included in the model. In subsequent periods, these bounds are computed as a function of past consumption and recycling parameters (see sections on recycling).

Perfectly elastic supply curves (i.e., $\lambda = \infty$) can be indicated in the worksheet by entering a base period (reservation) price and setting the appropriate price elasticity value to 0.00. This type of supply curve can be refined by specifying an upper bound on supplied quantity S^U. In dynamic projections, the shift variables will move horizontal supply curves up or down.

Table 3—Data for supply equations

B	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	******SUPPLY******														
3	A: Region number (01 to 99, in ascending order)														
4	B: Commodity number (01 to 99, in ascending order)														
5	C: Resource commodity number (optional, leave blank if omitted)														
6	D: Base period price in common currency														
7	E: Base period quantity supplied at price D														
8	F: Price elasticity (>0, enter 0.00 for horizontal supply)														
9	G: Elasticity of supply with respect to the first shift variable (optional, enter 0.00 if omitted)														
10	H: Elasticity of supply with respect to the second shift variable (optional, enter 0.00 if (omitted)														
11	I: Elasticity of supply with respect to the third shift variable (optional, enter 0.00 if omitted)														
12	J: Elasticity of supply with respect to previous-period supply (optional, enter 0.00 if omitted)														
13	K Elasticity of supply with respect to resource stock (optional, enter 0.00 if omitted)														
14	L: Lower bound on the quantity supplied (optional, enter 0.00 if omitted)														
15	M: Upper bound on the quantity supplied														
16	N: Price in the period before the base period														
17	O: Quantity supplied in the period before the base period														
18	reg	com	rcn	price	quant	P elast	Shift1	Shift2	Shift3	Pr sup	Res stk	Lobnd	upbnd	Prv price	Q(-1)
19	01	01	29	2.00	4.00	1.00	0.10	0.00	0.00	0.00	1.10	0	8	0.0	0.0
20	01	10		2.00	4.00	1.00	0.10	0.00	0.00	0.00	0.00	0	8	0.0	0.0

The supply curve described in line 19 of Table 3 for commodity 01 in region 01 is given at a price of 2.00 per unit (in common currency) with a quantity of 4 units and a price elasticity of 1.00. This supply is drawn from resource 29 in region 01 (see resource sheet). The elasticities of supply with respect to the three shift variables are 0.1, 0.0, and 0.0, respectively. The elasticity with respect to supply of the previous period is 0.0. The elasticity with respect to the growth of resource 29 from which this supply is drawn is 1.0, and the upper bound on the quantity supplied is 8. The minimum quantity to be supplied is not specified and is set to zero. The price and quantity from the previous period are also set to zero.

Resource—Worksheet D (Table 4) contains data that define the initial status of raw material. This worksheet is needed only in situations where the stock of raw materials needs to be monitored and where the stock may have an influence on the supply of commodities drawn from the resource. Note that resource number 99 is reserved.

The example in Table 4 shows resource 29 in region 01 with an initial inventory of 15 that grows periodically at a rate of 2%. Part of supply commodity 01 comes from this resource (20%), thus we can monitor the impact that this drain has on the resource. In addition, the change in the availability of this resource can influence future supply.

Table 4—Data for resource information

D	A	B	C	D	E	F	G	H	I	J	K	L	M
1	******RESOURCE******												
3	A: Region number (01 to 99, in ascending order)												
4	B: Resource commodity number (01 to 98, in ascending order within each region)												
5	C: Base period inventory												
6	D: Stock growth coefficient												
7	E: First supply commodity number (e.g., sawtimber)												
8	F: Percentage of first supply commodity obtained from inventory												
9	G: Second supply commodity number (leave blank if omitted)												
10	H: Percentage of second supply commodity obtained from inventory (enter 0.00 if omitted)												
11	I: Third supply commodity number (leave blank if omitted)												
12	J: Percentage of third supply commodity obtained from inventory (enter 0.00 if omitted)												
13	reg	rcn	inventory	growth	C1	ratio	C2	Ratio	C3	ratio			
14	01	29	15	1.02	01	0.20		0.0		0.0			
15													
16													

Manufacture—The Manufacture worksheet (Worksheet E in Table 5) contains data that define the manufacturing costs in a common currency (m_{jkpx}, in the objective function, Eq. (1)), the manufacturing coefficients (a_{jknpx} in the material balance constraints, Eq. (4)), and any by-product coefficients (b_{jbnpx} in the by-product constraints, Eq. (5)). Manufacturing costs are defined in M records, the manufacturing coefficients in P records, and the by-product coefficients in B records.

Records of the same type (i.e., M, P, or B) must be grouped together with M records entered first, followed by P records, and finally B records.

Within record type M, the data must be entered in ascending order: (1) by region, (2) by primary commodity within same region, (3) by secondary commodity within same primary commodity and region, (4) by process within same secondary and primary commodities of same region, and (5) by-product mix for the same process and secondary and primary commodities of the same region. Failure to do so may result in program errors.

Within record type P, the data must be entered in ascending order: (1) by region, (2) by output commodity within same region, (3) by input commodity within same output commodity of same region, (4) by process within same input commodity and output commodity of same region, and (5) by-product mix for the same process and input and output commodities of the same region. Failure to do so may result in program errors.

Table 5—Data for manufacturing costs, input-output coefficients, and by-product coefficients

E	A	B	C	D	E	F	G	H	I	J	K	L	M
1	******MANUFACTURE******												
3	A: Record type (three types of records are used, M, P, and B)												
4													
5	->Record type M (manufacturing cost):												
6	B: Region number (01 to 99, in ascending order)												
7	D: Commodity (primary) number (01 to 99, in ascending order within each region)												
8	E: Commodity (secondary) number (01 to 99, in ascending order within each region; leave blank if not applicable												
9	F: Process number (01 to 99, in ascending order within each commodity)												
10	G: Input mix number (1 to 9, in ascending order within each process)												
11	H: Net manufacturing cost in common currency												
12													
13	->Record type P (manufacturing coefficients):												
14	B: Region number (01 to 99, in ascending order)												
15	D: Input commodity number (01 to 99, in ascending order within each output commodity)												
16	E: Output commodity number (01 to 99, in ascending order within each region)												
17	F: Process number (01 to 99, in ascending order within each commodity)												
18	G: Input mix number (1 to 9, in ascending order within each process)												
19	H: Amount of input commodity per unit of output commodity												
20													
21	->Record type B (by-product coefficients):												
22	B: Region number (01 to 99, in ascending order)												
23	D: Primary commodity number (01 to 99, in ascending order within each output commodity)												
24	E: Secondary commodity number (01 to 99, in ascending order within each region)												
25	F: Process number (01 to 99, in ascending order within each region)												
26	G: Input mix number (1 to 9, in ascending order within each process)												
27	H: Amount of secondary commodity per unit of primary commodity												
28	M	reg		comm	byp	proc	m	Cost or coefficient					
29	M	02		02		01	1	1.00					
30	M	02		02	03	01	1	0.00					
31	M	02		04		02	1	–0.25					
32	M	02		12		22	1	1.00					
33	M	02		13		23	1	1.00					
34	P	02		01	02	01	1	2.00					
35	P	02		03	04	02	1	0.80					
36	P	02		10	12	22	1	2.00					
37	P	02		10	13	23	1	2.00					
38	B	02		02	03	01	1	0.50					

For record type B, data must be entered in ascending order (1) by region, (2) by primary commodity number within same region, (3) by secondary commodity within same primary commodity and region, (4) by process number for same secondary commodity, primary commodity, and region, and (5) by product mix for same process, secondary commodity, primary commodity, and region.

For the simple example shown in Table 5, five products (including two sub-commodities) are produced in manufacturing region 02. Each unit of primary product 02 produced by process 01 and input mix 1 requires 2 units of commodity 01 (line 34). The net manufacturing cost of one unit of primary product 02 by process 01, mix 1, is $1.00 (line 29). In the production of the primary product 02 by process 01, input mix 1, a by-product 03 is generated at the rate of 0.5 units per unit of primary product 02 produced at a cost of $0.0 per unit (line 30); 0.8 unit of by-product 03 is then manufactured into a unit of the secondary commodity 04 by process 02, mix 1 (line 35), resulting in a recovery in manufacturing costs of $0.25 per unit of 04 produced (line 31). The manufacture processes for two sub-commodities, commodities 12 and 13, of an aggregate demand commodity (commodity 05 in Table 2) are also defined. Their constraining relationship to the aggregate demand commodity is defined below in Table 8.

Capacity—For multi-period models, capacity information may need to be entered into two worksheets. If capacity change is estimated with the accelerator model (see

Dynamic Phase, Manufacturing Capacity, Accelerator Model), then both the Capacity 1 worksheet and the Capacity 2 worksheet will require data; if capacity change is estimated with the *q* model, only the Capacity 2 worksheet will require data and any data in the Capacity 1 worksheet will be ignored in program execution.

***Capacity 1*—**Worksheet F (Table 6) illustrates the format for defining the net change in global manufacturing capacity (i.e., total net change in capacity in all regions), from one period to the next, for each manufactured commodity. It is needed only for multi-period forecasts using the accelerator model of capacity change (option 4 of FPL–PELPS main menu). This global net change in capacity is a linear function of changes in global production in the three previous periods, as follows.

Net capacity change from t to $t+1$ =

b_1*(production change from $t-1$ to t) +

b_2*(production change from $t-2$ to $t-1$) +

b_3*(production change from $t-3$ to $t-2$)

where t represents the base period and b_1, b_2, b_3 are the three expansion parameters given in columns E, F, and G, respectively.

For further discussion and an example of the use of this worksheet, refer to the PELPS III manual (Zhang and others 1993). Although programming has been updated for this model in FPL–PELPS, it is unsupported at this time.

Capacity 2—Worksheet G (Table 7) contains data that define the level and change in manufacturing capacity. For a static model, it is only necessary to specify the manufacturing capacity in the base period. Further data must be specified for dynamic forecasts (option 4 or option 5 of the FPL–PELPS main menu) of capacity change.

If option 4 (Run multi-periods—accelerator model) is selected, only data from the first 10 columns (A to J) are needed and the other columns can be omitted (either left blank or filled with 0.00). Column I contains ω, the weight

Table 6—Worksheet for capacity change (accelerator model)

F	A	B	C	D	E	F	G	H	I	J	K	L	M
1	******CAPACITY—1******												
3	A:	Commodity number (01 to 99, in ascending order)											
4	B:	Production level one period before the base period											
5	C:	Production level two periods before the base period											
6	D:	Production level three periods before the base period											
7	E,F,G:	Expansion parameters											
8													
9													
10													
11													

of the q ratio in capacity allocation, and column J contains θ, the weight of past production (see eq. (38) in the *Accelerator Model* subsection of Changes in Manufacturing Capacity in PELPS III manual (Zhang and others 1993)). These parameters control the effect of the shadow price–capacity cost ratio and production level in distributing the changes in global manufacturing capacity among the regions and processes. Refer to the PELPS III manual for further details (Zhang and others 1993), but as noted previously, this feature is currently not supported in FPL–PELPS.

If option 5 (Run multi-periods—q model) is selected, all columns (except B and D) are required. Columns I to T contain b_{00jkp} to b_{33jkp}, the expansion parameters used in the prediction of the change in manufacturing capacity of a commodity by region and process (see Eq. (8)). In the q model, the relative gross change in capacity can be a linear function of the current ratio and up to four previous q ratios (columns Z, AA, AB, and AC), the lagged q-ratios relative to capacity (lagged capacities are entered in columns U through Y), and the previous relative gross change in capacity. (See Eq. (8) for further details.) An overtime process can be included as a function of another process such that the capacity of the overtime process will be calculated as function of the capacity of the parent process in dynamic forecasts; the specified capacity in column F will be used as the base period capacity for an overtime process.

The data must be entered in ascending order: (1) by region, (2) commodity, (3) process number (column E), and (4) overtime process number (column D). If there is no depreciation for a process, 0.00 must be entered as the depreciation rate. An overtime process for a commodity must immediately follow the associated parent process. For the overtime record, the parent process number is entered in column D and column E will contain the overtime process number.

The data in Table 7 define the manufacturing capacity constraints for a simple example. For instance, the manufacturing capacity of process 01 for commodity 02 in region 02 is 3 units, with a depreciation rate of 2%/period, and the cost of new capacity is \$0.5/unit in common currency. Capacity expansion parameters have been set to zero.

Table 7—Data for cost, physical depreciation, and capacity change (*q* model). Note data extends to AD column of worksheet

G	A	l	C	D	E	F	G	H	I	J	K	L	M	N	O
1	******CAPACITY—2******														
3	A:			Region number (in ascending order)											
5	C:			Commodity number (in ascending order in each region)											
6	D:			Process number (01 to 99, in ascending order within each commodity for overtime capacity; leave blank if not applicable)											
7	E:			Process number (01 to 99, in ascending order within each commodity)											
8	F:			Manufacturing capacity of base period											
9	G:			Capacity depreciation rate											
10	H:			Cost of new capacity in common currency (>0)											
11	I,J,...,T:			Expansion parameters											
12	U,V,...,Y:			Manufacturing capacity one period, two periods, ..., five periods before the base period, respectively											
13	Z,AA,AB,AC:			q ratio in one period, two periods, ..., before the base period (non-negative, enter -1.00 if not available, enter 0.00 if zero)											
14	AD:			ratio of overtime capacity to regular capacity											
15	Reg		com	otp	proc	cap	depr	Cost	C*q	E*q_{-1}	F*q_{-2}	G*q_{-3}	H*q_{-4}	I*q/C_{-1}	J*q/C_{-2}
16	02		02		01	3.0	0.02	0.5	0	0	0	0	0	0	0
17	02		04		02	2.0	0.02	0.5	0	0	0	0	0	0	0
18	02		12		22	3.0	0.02	0.5	0	0	0	0	0	0	0
19	02		13		23	3.0	0.02	0.5	0	0	0	0	0	0	0

Recycling (Demand)—Worksheet H (Table 8) contains data that define the fraction of recycled content within the total aggregate recycled commodity. The minimum recycled content restriction for the aggregate commodity is specified in the Demand worksheet (Table 2), while the minimum recycled content for each associated sub-commodity is defined in this worksheet. It is used to force consumption of a commodity to collectively consist of at least a specified fraction of recycled content. The data must be entered in ascending order: (1) by region, (2) aggregate commodity, and (3) sub-commodity. It is assumed that each sub-commodity has its own unique input mix (specified in the manufacturing process); however, this is not specified in worksheet H.

In the example in Table 8, the demand aggregate commodity 05 is subdivided into two "sub-commodities," one for each of two processes that result in different fractions of recycled content of the demanded aggregate commodity. These two sub-commodities are processed in the manufacturing region 02 (see Table 7) and then transported to the demand region 03 (see Table 10). Their cumulative recycled content must meet or exceed the content (0.85) specified for the aggregate commodity 05 in line 19 of Table 2.

Recycling (Supply)—The Recycling (Supply) worksheet (Worksheet I in Table 9) contains data that constrain the supply and utilization of recovered commodities in each region, i.e., the distribution of consumption by region, and the minimum and maximum fractions of recovered waste from a consumed commodity. These data are needed only for multi-period forecasts to impose constraints on the recovery of some commodities.

The lower and upper bounds on supply of the recovered waste for the base period must be entered in the Supply worksheet (Worksheet B in Table 3). Thereafter, FPL–PELPS will compute the bounds from past consumption and recovery rates entered in Worksheet I. The data must be entered in ascending order: (1) by region, (2) recycled commodity, and (3) consumed commodity.

The PELPS III manual (Zhang and others 1993) contains an example that illustrates commodity recycling constraints on the supply of a manufactured commodity.

Table 8—Data for commodity recycling constraints on demand

H	A	B	C	D	E	F	G	H	I	J	K	L	M
1	******RECYCLING (DEMAND)******												
3	A: Region number (01 to 99, in ascending order)												
4	C: Aggregate commodity number (01 to 99, in ascending order within each region)												
5	E: Sub-commodity number (01 to 99, in ascending order within each region)												
6	F: Input mix number (leave blank)												
7	G: Fraction of recycled content of the sub-commodity												
8	03		05		12		0.75						
9	03		05		13		1.00						
10													

Table 9—Data for commodity recycling constraints on supply

I	A	B	C	D	E	F	G	H	I	J	K	L	M
1	******RECYCLING (SUPPLY)******												
3	A: Region number (01 to 99, in ascending order)												
4	C: Recovered waste number (01 to 99, in ascending order within each region)												
5	E: Consumed commodity number (01 to 99, in ascending order within each recovered waste)												
6	F: Fraction of commodity consumed in each region												
7	G: Minimum fraction of recovered waste from consumed commodity												
8	H: Maximum fraction of recovered waste from consumed commodity												
9													
10													
11													

Transportation Cost and Tax—Worksheet J (Table 10) contains data that specifies inter-regional freight costs (in the common currency) and any import and export ad-valorem tax rates.

The data must be entered in ascending order: (1) by region of origin, (2) region of destination, and (3) commodity. Inter-regional transportation of commodities is permitted only between those regions explicitly specified in Worksheet J. Freight costs within a region must be included in the manufacturing costs and in the demand and supply prices used to define the associated curves.

The example in Table 10 defines transportation routes between regions. For example, line 10 shows a freight cost of $0.75/unit (in common currency) to transport one unit of commodity 01 from region 01 to region 02, with the import and export ad-valorem tax rates set at 2%. Total transportation costs T_t are then estimated by the system as freight costs F_t plus export and import taxes:

$$T_t = F_t + P_{t-1} * X_t^{\mathrm{e}} + (P_{t-1} + T_{t-1}) * X_t^{\mathrm{i}}$$

X_t^{e} and X_t^{i} represent the per unit export and import tax rates, respectively.

Exchange Rate—The Exchange Rate worksheet (Worksheet K in Table 11) contains data that specify the exchange rates in the base period, i.e., the rate at which the domestic prices and costs of a region are converted to the chosen common currency in the base period. An exchange rate is expressed as the ratio of the region's currency to the common currency. If exogenous changes are specified in the exchange rates for later periods, FPL–PELPS will modify prices and costs according to the formulas described in the dynamic phase modeling section.

The data must be entered in ascending order by region, and all demand, supply, and production regions must be included.

For the example in Table 11, the exchange rate between the currency of region 03 and the common currency is 1.1, such that 1.00 unit of the common currency is equal to 1.1 units of the region 03 currency. Similarly, the exchange rate of 1.0 shown for regions 01 and 02 indicates that prices and costs in these regions are already expressed in the common currency.

Table 10—Data for transportation costs and tax rates

J	A	B	C	D	E	F	G	H	I	J	K	L	M
1	******TRANSPORTATION COST AND TAX******												
3	A: Origin region number (01 to 99)												
4	C: Destination region number (01 to 99, in ascending order within each origin)												
5	E: Commodity number (01 to 99, in ascending order within each origin-destination)												
6	F: Freight cost of shipping one unit of commodity from origin to destination												
7	G: Import ad-valorem tax rate												
8	H: Export ad-valorem tax rate												
9	O_reg		D_reg		comm	cost	itax	otax					
10	01		02		01	0.75	0.02	0.02					
11	01		02		10	0.75	0.02	0.02					
12	02		03		02	0.75	0.00	0.00					
13	02		03		04	0.50	0.00	0.00					
14	02		03		12	0.75	0.00	0.00					
15	02		03		13	0.75	0.00	0.00					

Table 11—Data for exchange rates

K	A	B	C	D	E	F	G	H	I	J	K	L	M
1	******EXCHANGE RATE******												
3	A: Region number (including demand, supply, and production, 01 to 99)												
4	B: Exchange rate (expressed as the ratio of regional currency to common currency)												
5	reg	Rate											
6	01	1.00											
7	02	1.00											
8	03	1.10											

Exogenous Changes—Worksheet L (Table 12) contains data that specify the exogenous changes in various parameters from one period to the next in a multi-period model.

Table 12—Data for exogenous changes in demand, supply, resources, costs, technologies, capacities, depreciation, recycling, taxes, and exchange rates

L	A	B	C	D	E	F	G	]	]	J	]	L	M
1	******EXOGENOUS CHANGE******												
3	A: Data block name (the word PERIOD followed by an integer from 1 to 20)												
4	A: Record type (thirteen types of records are used: D,S,I,M,P,B,K,C,W,T,E)												
5													
6	->Record type D (shift of the demand curve):												
7	B: Region number												
8	D: Commodity number												
9	H: Updated price elasticity (<0), enter 0.00 if unchanged												
10	I: Growth rate in value of currency												
11	J: Growth rate of the first demand shift variable												
12	K: Growth rate of the second demand shift variable												
13	L: Growth rate of the third demand shift variable												
14	M: Growth rate of the lower bound on the demanded commodity												
15	N: Updated minimum fraction of recycled content												
16													
17	->Record type S (shift of the supply curve):												
18	B: Region number												
19	D: Commodity number												
20	H: Updated price elasticity (>0), enter 0.00 if unchanged												
21	I: Growth rate in value of currency												
22	J: Growth rate of the first supply shift variable												
23	K: Growth rate of the second supply shift variable												
24	L: Growth rate of the third supply shift variable												
25	M: Growth rate with respect to the resource inventory												
26	N: Growth rate of the upper bound on the supplied commodity												
27													
28	-> Record type I (change in resource characteristics) :												
29	B : Region number												
30	D : Resource commodity number												
31	H: Updated growth stock coefficient												
32	I: Updated percentage of first commodity obtained from inventory, enter 0.00 if unchanged or omitted												
33	J: Updated percentage of second commodity obtained from inventory, enter 0.00 if unchanged or omitted												
34	K: Updated percentage of third commodity obtained from inventory, enter 0.00 if unchanged or omitted												
35													
36	->Record type M (change of manufacturing cost):												
37	B: Region number												
38	D: Primary Commodity number												
39	E: Secondary Commodity number												
40	F: Process number												
41	G: Input mix number												
42	H: Growth rate of real net manufacturing cost in domestic currency												
43													
44	->Record type P (new manufacturing coefficients)												
45	B: Region number												
46	D: Input commodity number												
47	E: Output commodity number												
48	F: Process number												
49	G: Input mix number												
50	H: Updated amount of input per unit of output												
51													

Table 12—Data for exogenous changes in demand, supply, resources, costs, technologies, capacities, depreciation, recycling, taxes, and exchange rates—con.

52			->Record type B (new by-product coefficients)											
53	B:		Region number											
54	D:		Primary commodity number											
55	E:		Secondary commodity number											
56	F:		Process number											
57	G:		Input mix number											
58	H:		Updated amount of by-product per unit of primary commodity											
59														
60			->Record type K (new capacity, depreciation rate, cost of capacity, and parameters):											
61	B:		Region number											
62	D:		Primary commodity number											
63	E:		Overtime commodity number											
64	F:		Process number											
65	H:		Updated manufacturing capacity, enter -1.00 if no change											
66	I:		Updated depreciation rate, enter 0.00 if no change											
67	J:		Updated capacity cost (>0), enter 0.00 if no change											
68	K,L,...,W:		Updated expansion parameters, enter 0.00 if no change											
69	X:		Updated overtime coefficient, enter 0.00 if no change											
70														
71			->Record type C (new recycling (demand) coefficient):											
72	B:		Region number											
73	D:		Aggregate commodity number											
74	F:		Recycled commodity number											
75	H:		Updated fraction of recycled commodity											
76														
77			->Record type W (new recycling (supply) coefficient):											
78	B:		Region number											
79	D:		Recovered waste number											
80	F:		Consumed commodity number											
81	H:		Updated fraction of commodity consumed in each region											
82	I:		Updated minimum fraction of recovered waste from consumed commodity											
83	J:		Updated maximum fraction of recovered waste from consumed commodity											
84														
85			-> Record type T (change of tax rate and transport cost):											
86	B:		Origin region number											
87	D:		Destination region number											
88	F:		Commodity number											
89	H:		Change in freight cost											
90	I:		Change in import ad-valorem tax rate											
91	J:		Change in export ad-valorem tax rate											
92														
93			->Record type E (change of exchange rate):											
94	B:		Region number											
95	H:		Change in exchange rate											
96	PERIOD1													
97	D	03		02				–1.05	0	0	0	0	0	0
98	S	01		01				0.00	0.01	0	0	0	0	0
99	I	01		29				1.02	0.00	0	0			
100	K	02		04		02		2.5	0	0	0	0	0	0
101	B	02		02	03	01	1	0.6						
102	E	01						0.01						

With data from this worksheet, FPL–PELPS can simulate changes in the model resulting from

- shifts of the demand curves (record type D),
- shifts of the supply curves (record type S)
- updated growth and drain coefficients of raw resources (record type I),
- changes in net manufacturing costs (record type M),
- new manufacturing coefficients (record type P),
- updated by-product coefficients (record type B),
- new capacities, depreciation rates, and capacity costs (record type K),
- new fractions of recycled commodities in the consumed commodities (record type C),
- new coefficients for recovered wastes (record type W),
- changes in freight costs, and import and export ad-valorem tax rates (record type T), and
- changes in exchange rates (record type E).

Note that changes for cross-price effects (record types L and N) are not available with FPL–PELPS.

Data are ordered by period. The data for each period in the worksheet begin with a record PERIOD*t*, where t is a positive integer indicating the period when changes are to be made. PERIOD1 must always be present for multi-period forecasts, whereas PERIODt, $t \geq 2$, is optional. If data for a period are absent but that period is within the multi-period forecast ($t \geq 2$), the program assumes the changes in that period are the same as those in the immediately preceding period ($t - 1$). Within the worksheet, there must be no blank records (lines) between or within periods.

Saving Data

Once the data have been entered into the worksheets, they are saved in ASCII text files that conform to the subdirectory location, file name, and record format required by the FPL–PELPS programs (see Appendix). The sample Lotus 1-2-3 file distributed with FPL–PELPS contains special macros (hidden in worksheet M) that do this. While in the worksheet press <Ctrl>m to activate the macro menu. A small menu should appear with the following options: SAVE, PRINT, QUIT, END.

The SAVE option will save each worksheet as an ASCII text file in the C:\TPELPS1 subdirectory in the required format. This is required whenever any data is updated so that FPL–PELPS has access to the latest changes.

The PRINT option will allow the worksheets to be printed to a default printer following the classic style of Lotus 1-2-3 menus. However, it may be preferable to use the print option directly from Lotus 1-2-3.

The QUIT option closes the small menu and returns control to Lotus 1-2-3.

The END option quits Lotus 1-2-3 through the classic style of Lotus 1-2-3 menus, however, it is preferable to exit the program directly from Lotus 1-2-3.

After saving the data, return to the FPL–PELPS window (either by left-clicking on it or left-clicking on its button on the taskbar). Press any key to indicate to FPL–PELPS that Lotus 1-2-3 is finished saving the data files. The main FPL–PELPS menu should reappear. At this point, several options are available.

Solving Base-Period Equilibrium

FPL–PELPS can be used to solve both static and dynamic competitive equilibria, depending on the option selected from the main menu. Selection of option 3 (Run base-period) from the main menu will compute only the base-period equilibrium using the data saved under option 1 (Edit or create input file).

Solving Multi-Period Equilibria

As described in the mathematical modeling section, FPL–PELPS has the ability to predict capacity changes endogenously based on either the accelerator model or the q model of capacity change. Either capacity model may be selected from the main menu. Both option 4 (Run multi-periods–accelerator model) and option 5 (Run multi-periods–q model) compute a multi-period forecast and update the data from one period to the next according to the endogenous capacity changes and other exogenous changes saved with option 1 (Edit or create input file).

Viewing Model Solutions

After FPL–PELPS has completed running the model, the main menu reappears in the FPL–PELPS window. At this point, the equilibrium solution can be viewed via Lotus 1-2-3. Start Lotus and open the file C:\TPELPS1\PELPS\SOLUTION.WK4.

This is a generic spreadsheet file containing macros that will read in the solution; a backup copy of this file should always be available.

Once this file is open, press <Ctrl>m to activate the main data retrieval menu. The main menu offers eight options: DEMAND, SUPPLY, MANUFACTURING, TRANSPORTATION, CAPACITY, SAVE, QUIT, and END. Selecting any option will display a submenu of choices related to the chosen option. Each choice in a submenu causes Lotus 1-2-3 to read in the appropriate FPL–PELPS output. The submenus for each main menu option are as follows:

For DEMAND:

- QUANTITY displays the equilibrium quantities demanded by region and commodity.
- PRICE displays the corresponding equilibrium demand prices by region and commodity.
- SAVE saves this subset of data to a file.
- QUIT returns control to the main macro window.

For SUPPLY:

- QUANTITY displays the equilibrium quantities supplied by region and commodity.
- PRICE displays the corresponding equilibrium supply prices by region and commodity.
- SAVE saves this subset of data to a file.
- QUIT returns control to the main macro window.

For MANUFACTURING:

- PROCESS displays the equilibrium quantities manufactured by region, commodity, and process.
- REGION displays the equilibrium quantities manufactured by region and commodity.
- COST displays the manufacturing costs by region, commodity, and process.
- SAVE saves this subset of data to a file.
- QUIT returns control to the main macro window.

For TRANSPORTATION:

- QUANTITY displays the equilibrium quantities transported between regions.
- COST displays the transportation costs between regions.
- SAVE saves this subset of data to a file.
- QUIT returns control to the main macro window.

For CAPACITY:

- PROCESS displays the manufacturing capacities by region, commodity, and process.
- REGION displays the manufacturing capacities by region and commodity.
- SHADOWPRICE displays the corresponding capacity shadow prices by region, commodity, and process.
- SAVE saves this subset of data to a file.
- QUIT returns control to the main macro window.

The SAVE option of the main macro window saves a range of the current worksheet into a file specified by the user. The current worksheet must be renamed when saving (use the Lotus 1-2-3 FILE–SAVE AS option) or the data will be lost.

The QUIT option of the main macro window quits the macro menus and returns control to Lotus 1-2-3.

The END option terminates Lotus 1-2-3. Be sure to save your solution before exiting Lotus as you may lose your data and have to re-run the model.

Quitting FPL–PELPS

To quit FPL–PELPS, choose option 7 (Quit FPL–PELPS) from the main menu. Then close the DOS window to return to Windows 95.

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Glossary

By-product or co-product. Material generated from the production of a primary commodity that may be considered as a secondary commodity or used in the production of a secondary commodity.

Consumed commodity. An output commodity demanded in the market (same as an end-product).

Demand region. A region in which consumption of an end product is modeled by a demand function, giving quantity demanded as a function of price.

Exchange rate. The value of a region's currency per unit of a common currency (relative to currency value of some period).

Export ad-valorem tax. The tariff imposed by a supply region on a commodity exported from the region.

Freight cost. The shipping cost of a commodity from one region to another.

Import ad-valorem tax. The tariff imposed by a demand region on a commodity imported to the region.

Input commodity. Commodity used in the production of an output commodity.

Input mix. A technically feasible combination of manufacturing inputs and costs that can be used to produce one unit of output by a given process.

Manufacturing coefficient. The amount of an input commodity needed to make a unit of output commodity.

Manufacturing cost. The per unit cost of producing a commodity by a specific process.

Manufacturing region. The region in which the production of a commodity, and the corresponding consumption of the commodities needed in making it, are modeled as a process.

Overtime process. Process where increased production is allowed as a percentage of regular capacity, but at increased cost, to temporarily increase capacity.

Primary raw material. An input commodity supplied in the market.

Process. The technology for making an output commodity represented by the manufacturing coefficients and the corresponding manufacturing costs.

Recovery rate. The ratio of recovered waste collected to new supply of the corresponding consumed commodity (new supply equals production plus imports less exports).

Recovered waste. A consumed commodity that is recycled after consumption, thus becoming an input commodity.

Recycled commodity. An end product made from previously consumed commodities.

Secondary commodity. A commodity produced as or from by-products of other processes.

Supply commodity. An input commodity supplied in the market.

Supply region. A region in which the supply of an input commodity is modeled by a supply function, giving quantity supplied as a function of price. Also, may be referred to as a production region.

Transportation cost. The sum of freight cost, and import and export taxes.

Virgin commodity. An end-product made primarily from raw (i.e., not recovered waste) materials.

Appendix—Input Record Definitions

This appendix defines the records for each ASCII (text) data file used as input into the FPL–PELPS program. The Lotus 1-2-3 macros save each worksheet as one of the following corresponding files in the C:\TPELPS1 subdirectory. For some users, it may be necessary to modify column widths in the worksheets so that Lotus will output the data correctly. The variables without column specifications are read in by the programs as numbers and thus only require a space to separate them from their neighboring variable. A common problem with Lotus is that the column width on a numeric column may not be wide enough for output of a particular number and Lotus will output a series of asterisks (******) in place of the number. This will cause run-time errors (106) in the FPL–PELPS programs. The offending column is easiest found by reviewing each of the following data files in the C:\TPELPS1 subdirectory:

DEMIN (from Demand worksheet)

Field	Column	Variable
1	1–2	Region
2	4–5	Commodity
3		Initial price
4		Initial quantity
5		Price elasticity
6		Shifter 1 elasticity
7		Shifter 2 elasticity
8		Shifter 3 elasticity
9		Elasticity with respect to last demand
10		Lower bound
11		Past price
12		Past quantity
13		Minimum recycled content

SUPIN (from Supply worksheet)

Field	Column	Variable
1	1–2	Region
2	4–5	Commodity
3	7–8	Resource commodity
4		Initial price
5		Initial quantity
6		Price elasticity
7		Shifter 1 Elasticity
8		Shifter 2 Elasticity
9		Shifter3 Elasticity
10		Elasticity with respect to last supply
11		Elasticity with respect to resource change
12		Lower bound
13		Upper bound
14		Past price
15		Past quantity

CROIN (Hidden worksheet for cross price elasticity - NOT USED IN FPL–PELPS. File should be empty with exception of <cr> in field 1, column 1.)

Field	Column	Variable
1	1	Record type
2	3–4	Region
3	6–7	Commodity 1
4	9–10	Commodity 2
5		Elasticity of commodity 1 with respect to commodity 2

RESIN (from Resource worksheet)

Field	Column	Variable
1	1–2	Region
2	4–5	Resource commodity
3		Inventory
4		Stock growth coefficient (gsc)
5	m	Blank
6	(m+1)–(m+2)	Supply commodity 1
7		Drain (whipple) coefficient 1
8	n	Blank
9	(n+1)–(n+2)	Supply commodity 2
10		Drain coefficient 2
11	q	Blank
12	(q+1)–(q+2)	Supply commodity 3
13		Drain coefficient 3

MATDAT (from Manufacture worksheet)

		Variables by record type		
Field	Column	M	P	B
1	1	Record type	Record type	Record type
2	3–4	Region	Region	Region
3	9–10	Primary commodity	Input commodity	Primary commodity
4	12–13	Secondary commodity	Output commodity	Secondary commodity
5	15–16	Process	Process	Process
6	18	Input mix	Input mix	Input mix
7		Cost	Input/output ratio	Sec/Prim ratio

MANPAR (from the Capacity 1 worksheet)

Field	Column	Variable
1	1–2	Commodity
2		Production lag one
3		Production lag two
4		Production lag three
5		Expansion parameter 1
6		Expansion parameter 2
7		Expansion parameter 3

DEPIN (from the Capacity 2 worksheet)

Field	Column	Variable
1	1–2	Region
2	7–8	Commodity
3	10–11	Blank (if not overtime process), primary process (if overtime process)
4	13–14	Primary process (if not overtime process), Overtime process (if OT process)
5		Capacity
6		Depreciation rate
7		Cost
8		Expansion parameter 1
9		Expansion parameter 2
10		Expansion parameter 3
11		Expansion parameter 4
12		Expansion parameter 5
13		Expansion parameter 6
14		Expansion parameter 7
15		Expansion parameter 8
16		Expansion parameter 9
17		Expansion parameter 10
18		Expansion parameter 11
19		RCG(-1)
20		Capacity lag one
21		Capacity lag two
22		Capacity lag three
23		Capacity lag four
24		Capacity lag five
25		*q*-ratio lag one
26		*q*-ratio lag two
27		*q*-ratio lag three
28		*q*-ratio lag four
29		Ratio of overtime capacity to regular capacity

REDIN (worksheet for Recycling Demand)

Field	Column	Variable
1	1–2	Region
2	7–8	Aggregate commodity
3	13–14	Sub-commodity
4	16	Input mix (leave blank)
5		Fraction recycled content

RECIN (worksheet for Recycling Supply)

Field	Column	Variable
1	1–2	Region
2	7–8	Recovered waste number
3	13–14	Consumed commodity
4		Fraction consumed
5		Minimum recovery rate
6		Maximum recovery rate

TRAIN (worksheet for Transportation Cost and Tax)

Field	Column	Variable
1	1–2	From region
2	7–8	To region
3	13–14	Commodity
4		Freight cost
5		Import tax rate
6		Export tax rate

TAXIN (also worksheet for Transportation Cost and Tax; first four fields only)

Field	Column	Variable
1	1–2	From region
2	7–8	To region
3	13–14	Commodity
4		Freight cost

EXCIN (worksheet for Exchange Rates)

Field	Column	Variable
1	1–2	Region
2		Exchange rate

UPIN (worksheet for Exogenous Changes—must have period separator for multi-period)

Field	Column	Variable
Record type D, Demand Change		
1	1	Record type
2	3–4	Region
3	9–10	Commodity
4		Updated price elasticity
5		Currency growth rate
6		Shifter 1 growth rate
7		Shifter 2 growth rate
8		Shifter 3 growth rate
9		Lower bound growth rate
10		Updated min recycled content
Record type S, Supply Change		
1	1	Record type
2	3–4	Region
3	9–10	Commodity
4		Updated price elasticity
5		Currency growth rate
6		Shifter 1 growth rate
7		Shifter 2 growth rate
8		Shifter 3 growth rate
9		New resource elasticity
10		Upper bound growth rate

UPIN (worksheet for Exogenous Changes; must have period separator for multi-period)—con.

Field	Column	Variable
Record Type I, Resource Change		
1	1	Record type
2	3–4	Region
3	9–10	Resource commodity
4		New stock growth coefficient
5		Commodity 1 drain percentage
6		Commodity 2 drain percentage
7		Commodity 3 drain percentage
Record Type M, Manufacturing Cost Change		
1	1	Record type
2	3–4	Region
3	9–10	Primary commodity
4	12–13	Secondary commodity
5	15–16	Process
6	18	Input mix
7		Cost growth rate
Record Type P, Manufacturing Coefficient Change		
1	1	Record type
2	3–4	Region
3	9–10	Input commodity
4	12–13	Output commodity
5	15–16	Process
6	18	Input mix
7		Updated input/output ratio
Record Type B, By-Product Change		
1	1	Record type
2	3–4	Region
3	9–10	Primary commodity
4	12–13	Secondary commodity
5	15–16	Process
6	18	Input mix
7		Updated secondary/primary ratio
Record Type K, Capacity 2 Change		
1	1	Record type
2	3–4	Region
3	9–10	Commodity
4	12–13	Primary process (if OT process)
5	15–16	Primary process (if OT process)
		Overtime process (if OT process)
6		Capacity
7		Depreciation rate
8		Cost
9		Expansion parameter 1
10		Expansion parameter 2
11		Expansion parameter 3
12		Expansion parameter 4
13		Expansion parameter 5
14		Expansion parameter 6
15		Expansion parameter 7
16		Expansion parameter 8
17		Expansion parameter 9
18		Expansion parameter 10
19		Expansion parameter 11
20		RCG(-1) parameter
21		Overtime ratio

UPIN (worksheet for Exogenous Changes; must have period separator for multi-period)—con.

Field	Column	Variable
Record Type C, Recycling Demand		
1	1	Record type
2	3–4	Region
3	9–10	Aggregate commodity
4	15–16	Sub-commodity
5	18	Input mix
6		Fraction Recycled Content
Record Type W, Recycling Supply		
1	1	Record type
2	3–4	Region
3	9–10	Recovered waste number
4	15–16	Consumed commodity
5		Fraction consumed
6		Minimum recovery rate
7		Maximum recovery rate
Record Type T, Transportation Change		
1	1	Record type
2	3–4	From region
3	9–10	To region
4	15–16	Commodity
5		Relative change in freight cost
6		Import tax rate
7		Export tax rate
Record Type E, Exchange Rate Change		
1	1	Record type
2	3–4	Region
3		Change in exchange rate
* The following cross price record should not be used in FPL–PELPS		
Record Type N, Demand Cross Price Change		
1	1	Record type
2	3–4	Region
3	9–10	Commodity 1
4	15–16	Commodity 2
5		Updated elasticity
* The following cross price record should not be used in FPL–PELPS		
Record Type L, Supply Cross Price Change		
1	1	Record type
2	3–4	Region
3	9–10	Commodity 1
4	15–16	Commodity 2
5		Updated elasticity