Chapter 2: Interindustry Macroeconomic Modeling

As the name implies, an Interindustry Macroeconomic (IM) model combines interindustry linkages and industry-level behavior in a macroeconomic framework. The model uses behavioral equations for individual industry and consumer activities and aggregates them to determine macroeconomic totals, such as Gross National Product and Equipment Investment.[1] Interindustry Macro models evolved from early work using input-output tables. The evolution of IM models, their basic structure, and how they compare to alternate modeling approaches are described in the first part of this chapter. To set the stage for developing industry-level income equations in following chapters, the latter part of the chapter focuses on price and income determination in an IM model and outlines this study's approach to modeling income by industry.

Early Development: Input-Output Modeling

The foundation of an IM model is the network of production relationships between industries described by an input-output table. An input-output table shows interindustry flows in an economy: the flow of oil to the steel industry, and the flow of steel to the auto

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[1] A similar combination of input-output and macroeconomic modeling is described in Klein (1986) and referred to as "Keynes-Leontief" modeling. Since "Keynes" implies a specific macro framework, and "Leontief" implies fixed input-output coefficients, the more general term "Interindustry Macroeconomic" model is adopted here.

industry. An input-output coefficient, $a_{i,j}$, shows how much of input i is used to make one unit of product j, or real per unit use.

The roots of input-output analysis are found as far back as the early eighteenth century, in the works of the French economist Francois Quesnay. Quesnay designed a <u>tableau economique</u> to illustrate the circular path of production and income among three sectors of the economy: agriculture, landlords, and manufacturers. The idea that an economy could be described by summarizing transactions among different participants was greeted by both enthusiasm and skepticism. In the eyes of Mirabeau, Quesnay's input-output table ranked as one of the world's three greatest discoveries, along with the invention of writing and money. (Gray, p. 93) Other economists found it unnecessarily complicated, and "It led Eugen Duhring to suspect Quesnay of some mathematical fantasy." (Sweezy, p. 865)   Aptly listed in the <u>International Encyclopedia of the Social Sciences</u> between "Innovation" and "Insanity", input-output has evolved from Quesnay's simple, hand-drawn illustration of a three-sector economy, into a powerful tool in economic modeling.

One of the important features of the <u>tableau</u>, or input-output table, is its explicit portrayal of an economic equilibrium.[2] In 1936, Wassily Leontief applied his research on input-output to the United

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[2] According to Schumpeter, "It would seem impossible to exaggerate the importance of this achievement if admiring disciples had not already done so." (Schumpeter, p. 242).

States economy and defined it as "an attempt to construct a Tableau Economique of the United States." (1941, p. 9) He stated that the purpose of later work was to apply the economic theory of general equilibrium to an empirical study of interrelations in an economy. (1953, p. 3) Giving empirical content to Walrasian general equilibrium theory was a breakthrough both for input-output analysis and for Walrasian economics.[3] In The Growth of Economic Thought, Henry Spiegel asserts that Walrasian economics seemed unable to acquire empirical content and become operational until input-output economics entered the picture.

> Input-output analysis gave numerical content to general equilibrium economics and demonstrated its practical usefulness in economic planning and forecasting. (p. 556)

One of the greatest impacts of Leontief's pioneering work, however, was the impetus it provided for further research in input-output and its use in econometric modeling.

Since Leontief's original work in the 1930's, input-output has expanded in several different directions. The four principal types of models that have developed are: Distributional, Real-Side Dynamic

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[3] This breakthrough was not immediately obvious, however. When Leontief came to Harvard, around 1931, it was with the condition that he be given a research assistant to make what today is called an input-output table. The Economics department agreed to the request but advised him by letter that no one in the department thought that such a project was feasible or of great value if completed.

(RSD), Computable General Equilibrium (CGE), and Interindustry Macroeconomic (IM) models.

All of these approaches include the "input-output equation" for determining output:

$$q = Aq + f \qquad (2.1)$$

or

$$q = (I - A)^{-1} f \qquad (2.2)$$

where
q = vector of product outputs,
A = matrix of input-output coefficients,
f = vector of final demands,
I = identity matrix.

In a Distributional model, the elements of the final demand vector, f, are determined without any reference to output, q. This method has been used to develop detailed forecasting models, such as the model of Data Resources, Inc., where the elements of the f vector come from multiplying variables from the aggregate model by a distributional matrix. Any change in the aggregate economy can be distributed to individual sectors via the input-output table to determine the impact of the change at a detailed level.

One problem with the Distributional model is its neglect of the influence of output growth on investment purchases. In equation 2.2, final demand does not respond directly to changes in production levels. However, investment decisions by firms clearly depend on current demand, as measured by production levels. In the Real-Side Dynamic models, the input-output equation was expanded, therefore, to take into account the interdependence of production and investment activity. For example, the Dynamic Leontief system is written:

where

x = vector of product outputs,
A = matrix of input-output coefficients,
B = matrix of capital to output coefficients,
x = vector of investment (change in capital stock),
f = vector of final demand.

Real-Side Dynamic models focus on using equation 2.3 to determine production and investment levels. Final demand, excluding investment, is taken as exogenous, as are the A-matrix coefficients.

A major problem in implementing RSD models was their explosive nature. Throughout the 1950's, Leontief was unable to get around this problem. The first solution seems to have been Almon (1961) who used a process based on a series expansion of the final demands. Later work, (Almon, 1966), improved the method of solution for models with forward-looking expectations. (This approach based on forward-looking expectations was called "consistent forecasting" by Almon and later called "rational expectations.") In Almon, et. al. (1974), the forward-looking expectations approach was replaced by an adaptive expectations approach, to get better forecasts.

One problem common to both Distributional models and RSD models is achieving an equilibrium solution. Consider a change in exports using either of these approaches. An increase in aggregate exports will imply an increase in exports of different products, such as cars, for example. Increased production of cars then implies higher demand for steel, plastic, electricity, and other inputs into making cars. More output of everything leads to more employment. But there the analysis stops. Does consumer demand then increase? Do prices rise? The Distributional and RSD models to not answer these questions. This incompleteness led to both the CGE and IM models.

Development of Interindustry Macroeconomic Approach

In the early 1960s, research on using the Real-Side Dynamic models coincided with two other developments in econometrics and led to the introduction of the Interindustry Macroeconomic modeling approach. The first development was research in developing multisectoral models to deal with prices and incomes. Leif Johansen (1960), for instance, developed a multi-sector model of the Norwegian economy that combined the use of input-output relationships in a framework to simultaneously determine rates of growth of output, employment, prices, and capital. Johansen's work laid the groundwork for Computable General Equilibrium models. Typically, these models have emphasized equilibrium, with little attention paid to the dependence of investment on growth. Similarly, the empirical work usually relies on rather informal methods to specify elasticities and then a single year to calibrate other parameters. They have been applied in countries where data is scarce but understanding of basic economic reactions is important. The second development that led to the IM approach were the advances being made in applying econometric techniques to data to estimate historical behavioral relationships, and to combine estimated parameters into an econometric model.[4]

The Interindustry Macroeconomic (IM) model is based on the input-output equation, but rather than take final demand as given, an IM model uses behavioral equations to determine final demand, and combines those estimates with projections of the input-output coefficient matrix to solve for production. In addition, the model is closed with respect to income and prices by using the input-output dual equation that determines prices as the sum of material costs and value added. The equations that serve as the basis for an IM model are:

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[4] See, for instance, Bodkin et. al. who describes the development of macroeconometric models.

$$q = Aq + f \qquad (2.4)$$
$$p = pA + v \qquad (2.5)$$

where

q = vector of product outputs,
p = vector of product prices,
A = matrix of input-output coefficients,
f = vector of final demand by product,
v = vector of value added per unit of output by product.

In an Interindustry Macroeconomic model, real product output is determined by modeling the matrix of input-output coefficients and the components of final demand. Total final demand for each product is the sum of different final demands, such as personal consumption and investment. Ideally, each final demand component is estimated at the product level, so behavioral parameters will differ between products. Purchases of cars, for example, will respond differently to income changes than food purchases. Likewise, investment by the steel industry will respond to changes in interest rates differently than does investment by the plastics industry. This framework mimics the economy, as aggregate results are determined by summing individual sectoral-level behavior.

To determine product outputs, an IM model also needs projections of input-output coefficients. One frequent criticism of input-output modeling in general is an attack on the use of static coefficients to describe the economy. A single input-output table gives a clear, detailed snapshot of an economy at a point in time. Certainly, however, the subject of that picture changes over time. It is a gross simplification to build a model that forecasts ten years into the future but is based on the interindustry structure of today.

One of the advances in using input-output was Almon's development of a method to forecast input-output coefficients and incorporate the forecasts in a model's framework.[5] An IM model is designed to use projections of coefficients that reflect changes in technology and interindustry relationships that occur over time. The coefficients are forecast outside the scope of the IM model and do not respond to changes in the model itself.

On one hand, it is a significant improvement in input-output modeling to use coefficients that change over time. On the other hand, the coefficients do not respond to any of the changes that the model forecasts. Over the long run, it may be reasonable to assume that changes in energy costs, for instance, will affect technological relationships. Attempts to incorporate dynamic coefficient response in a model with much sectoral detail have been largely unsuccessful, however, because of the difficulty of obtaining reliable econometric measures of the sensitivity of the coefficients to price changes.[6] The next best alternative is to view coefficient change as an exogenous

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[5] See Almon et. al., 1974.

[6] See Taylor, 1981.

assumption for the model. The framework of an IM model allows for running the model under various assumptions about coefficient change. In a forecast based on differing energy costs, for instance, coefficient projections can be modified to reflect energy-induced changes in interindustry structure.

Closing the model: prices and incomes

Product prices are determined by two types of costs: the costs of inputs and the costs of factors of production. Returns to factors of production, or value-added, include labor and capital income, as well as the portion of income that accrues to the government in business taxes. The cost of material inputs is determined by multiplying a vector of product prices by the inputs summarized in a column of the input-output coefficient matrix. Defining unit price as the sum of unit costs and then solving for prices yields the following equation

$$p = v\,(I - A)^{-1} \qquad (2.6)$$

where

p = vector of unit prices for products,
v = vector of unit value-added by product,
A = matrix of input-output coefficients,
I = identity matrix.

Product prices are determined by combining estimates of input-output coefficients with estimates of per unit value added. As in modeling final demands, the components of value added are ideally modeled at the detailed product or industry level.

Behavioral parameters for profits of the steel and plastics industries will differ, for example, as will the determinants of labor compensation in the textile and auto industries.

Summary: the Structure of an Interindustry Macroeconomic Model

The primal and dual input-output equations, combined with forecasts of input-output coefficients and industry-level final demand and income, define the bulk of an IM model. One type of economic activity not yet addressed by this structure is employment. To forecast employment by industry, output by product first is combined with estimates of industry labor productivity, in order to model labor requirements by industry. Combining these labor requirements with projections on the size of the labor force yields employment by industry.

In addition to a myriad of industry-level behavioral equations, an IM model also uses aggregate equations that serve two purposes. On one hand are aggregate equations needed to maintain any accounting relationships. Disposable income must be calculated as personal income less personal income taxes and non-tax payments, for example. On the other hand are equations that maintain key macro relationships. For instance, the IM model of the U.S. economy in this study includes macro equations for the savings rate, as well as for the aggregate manufacturing wage rate. Another important piece of the macro foundations of the model is the determination of interest rates and/or the money supply. The completed IM structure provides a consistent, closed, and dynamic model of an economy.

The specific IM model used for this study is the Long-term Interindustry Forecasting Tool (LIFT).[7] It was developed over the past twenty-five years at the Interindustry Forecasting Project at the University of Maryland (INFORUM), which is a not-for-profit research and consulting group directed by Clopper Almon. LIFT combines over one-thousand equations to forecast the U.S. economy and its industry detail. The goal of this thesis is to improve the price-income side of the model.

A Closer Look at the Price-income Side of an IM Model

As described above, an IM model uses the input-output dual equation to determine prices. The equation is based on the definition of price as the sum of two costs: costs of materials and returns to factors of production. According to equation 2.6, modeling prices is a straightforward process of combining input-output coefficients with estimates of unit value-added. In practice, integrating price determination into an interindustry macro model has proven to be a less-than-straightforward econometric challenge.

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[7] See McCarthy (1991) for a recent description of LIFT. See also Chapter 6 below.

A brief history of modeling prices and incomes

No attempt will be made here to provide an encyclopedic review of previous approaches to price-income determination in IM models.[8] Instead, a short description of some of the unique characteristics of price-income modeling will be presented, as well as the highlights of previous modeling attempts, to give perspective to the plan of approach for this work. The unique characteristics of price-income modeling that are discussed are: industry and product income data; exogenous and model-determined prices; and the industry income components.

Industry vs Product Income Data

One of the complications of modeling prices arises because of methods of collecting income data. The dual input-output equation defines product prices in terms of unit value added, or value added per dollar of output of any product. To model prices, then, value added must be available by product. In the U.S. National Income and Product Accounts (NIPA), however, value added data is only collected by <u>industry</u>. An industry is defined as a group of establishments engaged in the production of a similar product. Since any single industry may manufacture more than one product, the relationship between product and industry classifications must

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[8] See Hyle for a comprehensive summary of previous work on the LIFT model at the University of Maryland.

be summarized in a bridge table. This product-to-industry bridge defines the product composition of every industry's output.[9] In other words, each industry produces some "primary" product, as well as some "secondary" products. The value added from producing each of these products is allocated to the appropriate product columns of the bridge matrix. The Agriculture industry may not only harvest grain (its "primary" product), it may also produce ice-cream (a "secondary" product).   The income from the Agriculture industry would be spread to both Agricultural products (grain) and Food and tobacco processing products (ice cream). In addition, the product-to-industry bridge accounts for differences in product and industry definitions. For example, NIPA lists product and industry sectors named "Agriculture, forestry, and fisheries." The product-to-industry match is not exact, however, because Veterinary services are counted as part of the 'product' of Agriculture, but as part of a different 'industry', Medical services.

Exogenous vs Model-Determined Prices

A second complication of modeling the price-income side of an IM model arises when the possibility of specifying prices exogenously is introduced. In the IM model scheme, prices are determined by first solving for industry value added. In practice, a modeler may

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[9] See Hyle for the development of the product-to-industry bridge currently used in the model for this study. Hyle's work is based on information from the Department of Commerce.

choose to override a value-added-determined price and specify a product price exogenously. This possibility could arise for two reasons.

1) Exogenous price specification

In some instances, the appropriate level for a price may be determined by factors outside the scope of the model. For instance, the price of agricultural goods depends largely on the weather and on government policy. Since forecasting either the weather or the actions of government policy makers is beyond the capabilities of most economic modelers, it is desirable to specify agricultural prices exogenously.

2) Price simulations

Models are best used not merely as forecasting tools, but also as simulation tools for exploring different scenarios in a consistent econometric framework. To simulate different price shocks, then, it is necessary to override a value-added-determined price and specify an alternate price for any product.

If a product price is set exogenously, value added must be adjusted to insure that the input-output accounting of equation 2.2 is maintained.   In effect, this type of adjustment introduces a second product-to-industry bridge that distributes the effects of changes in product prices to the appropriate industries.[10] It is good to keep in mind that allowing prices other than value-added-determined prices implies that results of income by industry equations may be overridden.

Industry Income Components

To model product prices using the Interindustry Macroeconomic structure, income by industry must be estimated. In its most general sense, industry income is simply the value added to the cost of materials in the production of goods and services. That value added can be summarized as the returns to three factors of production: labor, capital, and government. In this study, value added is broken into twelve components:

- Labor compensation

- Returns to capital
  - Corporate profits
  - Proprietor income
  - Corporate and Non-corporate depreciation allowances
  - Corporate and Non-corporate inventory valuation adjustments
  - Net interest payments
  - Business transfer payments

- Rental income

- Returns to government

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[10] This raises a number of technical modeling issues that are addressed in Monaco, L.S..

Indirect business taxes
Government subsidies

Since labor compensation has been adequately covered in previous work, the bulk of this study concerns returns to capital and government.[11] Of these latter two, returns to capital are the most important in terms of their share of value added and their role in price determination.

Approaches to Modeling Return to Capital

This section describes two methods for modeling return to capital, emphasizing the problems encountered in each approach, to introduce the method for this study.

Return to capital can be viewed as an aggregate income source for every industry, or it can be examined more closely as the sum of its parts. One approach to modeling return to capital emphasizes the first point of view. In this approach, equations for total capital income by industry are estimated. Capital income includes volatile items, such as profits, as well as more stable items, such as net interest payments. Net interest and depreciation allowances are largely determined by historical factors, and move fairly steadily over the business cycle. Profits and proprietor income,

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[11] See Hyle Chapter 3 for industry results, and Monaco R.M. Chapter 5 for aggregate equation.

on the other hand, are prime indicators of business cycle movement. Because total capital income contains both type of items, it tends to be smoother than profits or proprietor income, and is therefore somewhat easier to estimate than the pieces. The main advantage of estimating total return to capital is that the division between interest and corporate profits depends on choices between debt and equity financing, which are difficult to model. By concentrating on their sum, the choice does not affect total value added. In addition to modeling total capital income, however, the components also must be modeled. In earlier versions of the model used for this study, each component of capital income was estimated separately.[12]   The total of the individual components was then summed, and the difference between that total and the result of the equation for total capital income was spread to the largest income components. In other words, the equations for total return to capital determined capital income for each industry, and the equations for the pieces of income determined the share of each component in the total.

One obvious disadvantage of this aggregate-plus-component approach is its redundancy. Profits are a relatively large component of capital income, and movements in profits dominate cycles in return to capital. Profit equations consequently resemble equations

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[12] See Monaco, R.M., pp. 91-98.

for total capital income. Two sets of equations are being used to do essentially the same task. In addition, the results of the equations for any component, such as profits, are being overridden by the capital equation. As noted earlier, value-added results in an IM model may also be overridden when prices are set exogenously, so the effectiveness of the industry income equations is diminished.[13] The practical issue this raises concerns the tractability of the model. The estimated equations often had little to do with the final forecast result, making it difficult to analyze forecast results.

Figure 2.1 illustrates the type of problem that resulted from aggregate-plus-component approach, by showing forecast results from the January 1989 version of the LIFT model. The profit margin for the Motor vehicle industry is shown. While the overall forecast of the U.S. economy produced by LIFT was reasonable, including product prices and total industry capital income, the individual income components often follow an unreasonable path. After more than twenty years on a downward trend, the profit margin for the auto industry reverses direction and grows rapidly through the entire forecast. It seems unlikely that profits in the troubled auto industry would enjoy such an optimistic outlook.

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[13] If one were wedded to the idea of using aggregate RTK equations and component equations, a better approach would use share equations for the components.

To avoid the problem of redundancy in income determination, Hyle estimated aggregate return to capital equations and equations for all components of capital income except profits. Profits were then calculated as a residual. (Hyle, ch. 4) Because aggregate equations mask movements in the individual pieces, however, the Hyle approach failed to capture adequately the changing share of the components of return to capital. For instance, while net interest payments have increased as a share of total return to capital, at the expense of corporate profits, the Hyle forecasts failed to capture that switch. (Hyle, ch. 6) The Hyle approach illustrates that the philosophy of IM modeling - what happens at the detailed level matters - aptly applies to forecasting capital income. Since capital income is comprised of disparate series, an efficient modeling approach puts behavioral results at the greatest level of detail possible.

To avoid redundancy and to emphasize the importance of building to the aggregate by focusing on the detail, this study will model total capital income for each industry as the sum of the different income components. Directly estimating equations for each of the components of capital income allows a conceptually simpler modeling approach. The factors that affect each component can be isolated and used appropriately. How to model those factors at the industry level is the next step in developing the price-income side of an IM model.

Approaches to Industry Equations

An IM model combines industry-level equations for components of final demand, such as consumption and investment, as well as components of factor income, such as profits and labor compensation. For some of these items, industry-level behavior can be estimated successfully using a single-specification. That is, a single functional form is appropriate for all industries, with parameter values capturing industry differences. A single specification is useful where the dependent variables are, in theory, jointly determined by the same variables. For example, Personal Consumption Expenditures (PCE) on various products depend on relative prices, disposable income, and demographic variables. Each PCE equation uses the same variables, but income and price elasticities differ by commodity.

An alternate approach uses an aggregate equation to summarize the overall behavior of the item, and then estimates industry behavior relative to the aggregate. This approach proves useful for at least two reasons. In some instances, a behavioral variable may be important at the aggregate level, but may be difficult to use at the detailed level. In estimating labor compensation, for instance, it is possible to model the link between money and prices by including monetary variables in the overall manufacturing wage rate. Monetary variables are significant in an aggregate equation, but difficult to use in sectoral wage equations. In this case, it is useful to estimate an equation for aggregate wages that includes a monetary link. Industry wages are then estimated relative to the aggregate wage using sector-specific variables. This approach also is attractive when data is available at an aggregate level that is not available at the industry level. In estimating Inventory Valuation Adjustments (IVA), for instance, the total change in business inventories in the economy is readily available. Detailed change in inventories by industry is not as easily available, however, so it is more difficult to estimate industry-level IVA equations. It is more convenient to estimate an aggregate IVA equation, and then estimate industry IVA relative to the total.

Both approaches assume that each industry's behavior can be summarized by the same functional form, with differing values for behavioral parameters. In some instances, however, specifying a single functional form for all industries is too restrictive. In estimating return to capital by industry, for instance, Hyle started with a single function for all industries. He found however, that many industries did not conform to that specification, so additional variables needed to be introduced for each industry.[14]

Although Edward Leamer did not specifically address the issue of estimating a set of industry equations, he proposes a flexible estimation procedure that represents the opposite extreme of using a single-specification approach. (Leamer, pp.308-313)   Leamer proposes that functional form and equation specification should be variable factors in the overall estimation process.   Instead of choosing an equation specification and then performing a regression, Leamer proposes experimenting with different functional forms, variables, and specifications. Ideally, the entire set of possible models would be tested. Since practical limitations

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[14] This is a common way of allowing industry-specific variables in a system that starts with a single function for each industry. In the case of return to capital equations, the equations of many industries were improved by the introduction of a number of different variables.

preclude such testing, Leamer suggests a piecemeal approach that tests the model with respect to a limited number of its dimensions. An important aspect of this limited testing is the extra knowledge that the researcher brings to the study. For example, part of the testing involves distinguishing two types of independent variables. So-called free variables are those which are always included in the equation. On the other hand are those variables the researcher feels comfortable experimenting with, or the doubtful variables. The distinction between free and doubtful variables should not be arbitrary, Leamer believes, but rather

> the split should be selected to represent as accurately as possible the other relevant information that is required to draw sensible inferences from the given data set. (p. 312)

In other words, the entire set of possible equations can be narrowed by an appropriate choice of doubtful and free variables.

Leamer's approach can be applied to industry equations for an IM model in the following manner. Instead of specifying a single functional form for all industries, a general functional form will be identified. The general function will include both free and doubtful variables, and each industry's equation will be estimated separately.

For example, this study uses a flexible industry approach for estimating profit income. A general set of variables is suggested for profit equations, but unlike previous studies, the equations will not be estimated with a single equation specification. Instead, industry-specific traits will play a role in determining the form of the equation.

Evaluating Equations to be Used in a Model

The usual approach to estimating econometric equations involves some attempt to evaluate the quality of the equation, both econometrically and in terms of economic theory. Standard diagnostics, R^2 and t-statistics, evaluate the econometric fit of the equation and statistical importance of variables. Economic theory judges the appropriateness of variables based on the interpretation of equation parameters. However, equations that are reasonable both econometrically and theoretically often combine in a model to produce results that are unreasonable.[15] In addition, Leamer notes that, in some instances, more than one specification of an equation will produce "reasonable" results. In those cases, additional information supplied by the researcher should be used to select an equation.

In earlier attempts to develop the price-income side of an IM model, equations for industry income passed rigorous tests of econometric integrity and economic reasonableness. When introduced into an IM model, an economically sound forecast was

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[15] See Almon (1989), as well as Monaco, R., chapter 4, Hyle Chapter 6.

generated. The forecasting properties of the model were not robust, however, to different exogenous assumptions for the IM model. In doing relatively simple exercises with the model, such as simulating changes in monetary policy, the model either broke down completely, or produced results that were economically unreasonable. (Hyle, chapter 6)

In the present study, emphasis is placed on evaluating the robustness of the equations once they are combined into the entire IM model.   In estimating equations, standard diagnostic and economic tests will be used. In addition, static forecasts of the equations will be used to evaluate the overall reasonableness of the equations. Finally, the equations will be included in the model and used to forecast under a number of different assumptions about the economy. This last step will be viewed as part of the development of the equations, in order to test their long-run forecasting properties.