MOODY'S ANALYTICS

April 2015

U.S. Macro Model Methodology

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Abstract

The Moody's Analytics economic, financial and demographic projections for the U.S. are produced each month using a large-scale econometric model. This article describes the specification of the U.S. national model.

In the broadest sense, aggregate economic activity is determined by the intersection of the economy's aggregate demand and supply functions. In the short run, fluctuations in economic activity are primarily determined by shifts in aggregate demand. The level of resources and technology available for production is taken as given. Prices and wages adjust slowly to equate aggregate demand with the level of activity the economy can potentially supply.

In the longer term, changes in aggregate supply determine the economy's growth potential. The two principal determinants of long-run economic growth are the rate of expansion of labor and capital, and changes in technology, which allow those inputs to be transformed into economic output more efficiently. The U.S. Macro Model is specified to reflect the interaction between aggregate demand and supply.

The model contains more than 1,800 variables, including unpublished intermediate variables, and is designed to produce forecasts that run 30 years. In addition to producing good cyclical near-term forecasts and stable long-run equilibrium, the forecast is designed to allow for scenario construction. Moody's Analytics produces a number of alternative scenarios each month, scenarios provided by regulators for bank stress-testing purposes, and clients produce many more.

Theory in brief

The macroeconomics profession continues to enjoy spirited methodological debates, but over the last few decades, heated arguments over the most appropriate way to model the economy have evolved toward a consensus view best described as "Keynesian in the short run, and classical in the long run."

In this view, the state of the economy is determined through the simultaneous relationship between three key variables: GDP growth, price inflation and interest rates. Specifically:

- GDP depends on aggregate spending, which in turn depends on the expected real rate of interest, or the nominal interest rate less future inflation;
- Nominal interest rates are determined both by monetary policy and by private demand for credit, both of which are influenced by GDP;
- Inflation is determined by firm price-setting choices, which depend on the level of real activity and inflation expectations.

Mathematically, this describes a system of three equations that can be solved for the three unknowns—real GDP, nominal interest rates, and inflation—conditional on given expectations of future income and inflation.

The classical long-run equilibrium is achieved at the point where expectations are consistent with reality; when this occurs, the level of real output, interest rates and inflation remain stable at equilibrium values governed entirely by the supply side of the economy.

In the short run, however, a shock to any part of this system can cause spending and inflation to depart from expectations; this, accordingly, causes departures in current growth, interest and inflation rates from their long-run equilibrium values, giving rise to the business cycle.

Theory vs. data

The modern consensus view does not extend to a consensus in econometric practice. This is because a fundamental difficulty prevents a direct application of the consensus story to the data: Expectations are central, and these are difficult to quantify and to forecast. As a result, there is not one, but three, distinct approaches to modeling the macroeconomy, all in common use today:

- At one end of the spectrum are pure time-series methods that require few, if any, assumptions from economic theory. These methods rely on highly flexible, reduced form specifications that "let the data speak."
- On the opposite end is a set of models that are built up from strict foundations in microeconomic theory and draw insights by imposing strict assumptions of economic theory upon the data rather trying to "fit" that data.
- In the middle of these extremes, balancing theoretical assumptions with empirical evidence, lies the traditional approach of building large-scale, multi-equation structural models of the economy.

The Moody's Analytics U.S. Macro Model relies most on the third approach: specifying, estimating, and then solving simultaneously a large set of equations that mirror the structural workings of the U.S. economy. On occasion, however, this approach is complemented by alternative modeling approaches. Just as there is no best tool in a carpenter's toolbox, there is no best model to employ in forecasting: Each approach has its own strengths and weaknesses, and whether or not it is appropriate to use depends on the task at hand. Understanding why and when one modeling approach may be favored over another requires an understanding of the trade-offs inherent in each approach.

Weighing the trade-offs

The vector autoregression, or VAR, model is the most common example of the first pure time-series approach to macroeconomic forecasting. A VAR forecast is obtained through a simple projection of future values on past information. Unlike in a structural model, where theoretical reasoning would determine how the relationships between GDP, interest rates and inflation rates are specified, in a VAR these three variables would simply be regressed on their own lagged values and those of the other variables, with no attempt to impose or infer any type of causal explanation for empirically observed correlations among the variables.

This lack of theoretical motivation is both the strength and weakness of the VAR. By emphasizing a close fit of historical relationships in the data over a priori reasoning, VARs are relatively immune to criticisms of "misspecification" from incorrect theory. VARs also tend to produce very accurate forecasts over short sample periods, as well as predict the dynamic responses of multiple variables in response to a common shock.

This method suffers from three limitations, however. First, the forecasts are difficult to explain intuitively; the lack of theory and large number of regressors make the model largely a black box. Second, the high degree of parameterization in a VAR reduces the efficiency of the resulting parameter estimates, and it limits the number of variables that can be forecast practically. A typical VAR incorporates only a few endogenous variables, providing a very limited view of the economy compared with the many hundreds of endogenous variables forecast in the Moody's Analytics U.S. Macro Model. Third, prioritizing experience over theory makes VARs less capable of incorporating possibilities outside the scope of experience (for example, so-called black swan events).

The two most common examples of the second, "microfoundations" approach include deterministic real business cycle models and, more recently, dynamic stochastic general equilibrium models. In these, model equations are derived from equilibrium expressions that relate observed aggregate outcomes to the solutions to the multiple inter-temporal dynamic optimization problems of individual consumers and firms. These models are theoretically elegant, allowing individuals rational, forward-looking, optimizing behavior such that actions, outcomes and expectations converge iteratively to find a solution that is mutually consistent.

The incorporation of microfoundations and rational expectations comes at a high computational cost, however. As a result, it becomes highly cumbersome to model and forecast more than a handful of variables. As with VARs, this limits their practical value. Deriving tractable model solutions also requires strong assumptions (for instance, that all consumers and firms are identical, each with very specific, simple preferences or production technologies). As a result, DSGE models remain most popular within academic circles, where priority of attention in model design is given to the means, rather than ends.

The limitations of VARs and DSGEs, particularly the narrow scope of series that can be included directly in the models, have sustained the popularity of structural macroeconometric models among most private and government forecasters for more than a half-century. The foundation of these models are the equations found in standard textbook macroeconomic theory, roughly the IS/LM model of aggregate demand and a Phillips curve relationship determining aggregate supply. These textbook equations are made operational as forecasting tools by econometrically estimating the parameters in the theoretical relationship to find the right "fit" in the observed data.

By taking a middle ground between theory and data, this approach attains neither the theoretical elegance of the DSGE approach or the empirical flexibility of a VAR. At the same time, however, it manages to avoid the shortcomings of either one; imposing theory to restrict the flexibility of econometric specifications allows more efficient estimation and greater explanatory power than a VAR can achieve. However, structural macroeconomic models do not require some of the extreme and somewhat unrealistic assumptions that render DSGEs susceptible to misspecification.

Nevertheless, the greatest advantage of these models is the great detail they can provide. Though VARs and DSGEs can incorporate no more than a few variables of interest such as aggregate GDP, a benchmark bond yield, and CPI inflation, structural macroeconomic models are able to specify and generate forecasts for a rich array of macroeconomic data, detailing the composition of both spending and industrial activity, the entire maturity yield curve and many other interest rates, and prices for goods, services and assets throughout the economy.

This approach is not without some costs, of course. Because of the mutual dependency of so many variables, care and caution must be taken when specifying and estimating equations to ensure both the validity of the coefficient estimates as causal relationships and the stability of the entire system.

The difficulty of interpreting empirical relationships in the model equations as true structural relationships in the economy was subjected to a well-known critique by the Nobel laureate Robert Lucas. In response, Moody's Analytics, like many forecasters employing these models, often rely on correlations of current and lagged variables, rather than contemporaneous correlations, to reduce problems of endogeneity bias.

In further contrast to VARs and DSGEs, structural macroeconomic models typically rely more heavily on exogenous forecasts and assumptions introduced from outside the model. Examples include demographic projections, assumptions regarding the pace of technological change, fiscal and monetary policy action, and global oil prices. These assumptions allow forecasters to incorporate information that is known, but not internal to the model, far more easily than in VARs and DSGEs.

Selecting the right tool

Macroeconomic models are built to serve three basic functions: producing useful forecasts, calculating counterfactuals to answer hypothetical ("what if") questions, and providing a transparent understanding of the current and future state of the economy.

Each of the three approaches to macroeconomic modeling detailed above have distinct strengths and weaknesses, which make each more appropriate for some tasks and less for others. Unaided by human input, VARs typically produce the most accurate forecasts, but practical constraints on the number of variables that can be included in a VAR reduce their value. DSGEs excel at evaluating counterfactual outcomes under alternative policies, because they take the greatest care in identifying theoretical causality from empirical correlation. VARs and DSGEs alike operate very much like a black box, however, which limits their value as an explanatory tool. To a great extent, their predictions must simply be taken at face value, as it is difficult to trace a path from the model's assumptions to its conclusions.

Structural macroeconomic models such as the Moody's Analytics U.S. model excel in exploring the economy-wide implications of alternative assumptions about the future, including those used in stress-testing exercises. In regulatory stress-testing, financial institutions are tasked with estimating portfolio loss under a range of macroeconomic assumptions regarding different rates of interest, GDP growth, unemployment and inflation. Rarely do bank balance sheets depend closely on these broad macroeconomic aggregates, however. More often, bank solvency hinges on asset prices, industrial performance and employment in certain seg-

Table 1:
Consumer Spending on Services

Quarterly data from 1977:4 to 2013:1
R Bar Squared = 0.296
Durbin-Watson statistic = 1.322

Dependent variable: dlog(Real personal consumption of services per person)

	Coefficient	T-Statistic
dlog(4-qtr MA(Household net worth: Real estate and non-real estate assets per person))	0.099	4.308
dlog(4-qtr MA(Real disposable income per person))	0.661	10.768
dlog(Consumer confidence index)	0.006	2.338

Notes: dlog stands for simple difference of a natural logarithm

ments of the economy such as the housing or commercial real estate market.

In such instances, the goal is not to produce a forecast of GDP, unemployment and inflation but to take these as *given*, and then to extrapolate what implications would be for specific regions, markets and asset values. This robs VARs and DSGEs of their primary value while emphasizing their primary limitation. Conversely, these stress-testing exercises capitalize on the primary strength of traditional large-scale structural macroeconomic models while blunting their most common criticisms.

Consumer spending

Aggregate demand is disaggregated into consumption, business investment, international trade and government expenditures. Consumer spending is further disaggregated into spending on motor vehicles and parts, durable goods excluding motor vehicles, nondurable goods, and services. Each of these components is modeled on a per capita basis to account for population growth. These categories are modeled as a function of real income and real household net worth. Energy prices impact real consumption of vehicles, nondurable goods and services. Real cash flow from borrowing and capital gains impacts nondurable goods, and vehicle prices are important for vehicle spending. Consumer confidence impacts service spending. The equation for real consumer spending on services is shown in Table 1.

The model for vehicle spending has an intermediate step. Factors particular to the automobile market also have a significant influence on automobile purchases, so they are treated separately within the broader framework of consumer durable purchases. Light vehicle sales form a crucial cyclical component of consumer demand, as motor vehicles and parts account for almost one-half of total durable goods consumption. New unit vehicle sales are modeled first, and then real spending depends exclusively on vehicle sales. The vehicle sales model is shown in Table 2.

The components of durable goods excluding motor vehicles, nondurable goods and services are modeled separately but forced to sum to the appropriate aggregate category. Other variables including unemployment, consumer sentiment, demographic trends, home sales, and the price of the particular good or service relative to the prices of all consumer goods and services are included in these models.

Table 2:
Light-Vehicle Sales

Quarterly data from 1991:3 to 2013:1
R Bar Squared = 0.674

Dependent variable: log(Light vehicle sales per person)

	Coefficient	T-Statistic
Constant	-2.95	-7.384
log(Household net worth: Real estate and non-real estate assets per person, lag 1)	-0.759	-2.276
log(3-qtr MA(Ratio of new to used car prices))	-0.478	-1.976
log(Gasoline prices)	-0.331	-7.771
pdl(log(Household cash flow per person),1)	0.107	0.264
pdl(log(Household cash flow per person),2)	0.965	1.751
pdl(log(Household cash flow per person),3)	0.476	1.074

Notes: pdl(…,#) stands for a polynomial distributed lag of order #, log stands for natural logarithm

Table 3: Fixed Investment on Industrial Equipment

Quarterly data from 1990:3 to 2013:1
R Bar Squared = 0.152

Dependent variable: dlog(Real fixed investment on industrial equipment)

	Coefficient	T-Statistic
Constant	-0.154	-2.299
40-qtr MA(Interest on debt share of corporate asset financing plus return-on-equity share of corporate financing)	-0.003	-1.106
dlog(Ratio of Price deflator: Fixed investment on industrial equipment to Total benefits: Manufacturing, 1 lag)	-0.262	-0.809
dlog(12-qtr MA(Weighted exchange value of the dollar))	-1.204	-2.396
4-qtr MA(Capacity utilization: Manufacturing)	0.002	2.082
dlog(Real consumption)	2.138	3.191

Notes: dlog stands for simple difference of a natural logarithm

Service spending includes final consumption of nonprofit institutions serving households. This is consistent with the inclusion of nonprofit institutions within the household sector in government data since their primary function is to redistribute output among members of the household sector. Their consumption is also modeled on a per capita basis, but is driven by overall economic output.

Gross private domestic investment

Gross private domestic investment is divided into three distinctly different categories: residential construction, fixed business investment, and inventory investment. Not only is each of these determined by quite different factors, but each exhibits different cyclical patterns.

Residential construction is influenced by household formation growth; housing affordability, which is determined by mortgage rates, house prices, and income growth; tax law changes; consumer sentiment; and lending standards established by mortgage lenders. Measures of residential construction activity included in the Moody's Analytics macroeconomic model include single- and multifamily housing starts, existing-home sales, and several measures of house prices.

Fixed business investment is divided into four categories of equipment and software, three categories of intellectual property, and five categories of nonresidential structures. Business investment plays an important role in both the demand and supply sides of the economy. On the demand side, investment is a critical determinant of the business cycle because it responds to, and therefore amplifies, shifts in output. In the traditional accelerator/multiplier theory, the level of investment depends on the change in expected output; investment changes will in turn stimulate further movements in output through the multiplier effects.

Investment influences the supply side of the economy since it is the principal determinant of potential output and labor productivity. Investment spending not only adds to the stock of capital available per worker, but also determines the extent to which the capital stock embodies the latest and most efficient technology.

The specification of the investment equations is based on the neoclassical investment theory of the firm. Following this approach, net investment is modeled as a function of changes in expected output and the cost of capital. The cost of capital is equal to the implicit cost of leasing a capital asset, and therefore reflects the real after-tax cost of funds, tax and depreciation laws, and the price of the asset. Although most theoretical analyses assume that businesses do not face constraints on investment funds, in practice there are limits to the availability of credit. Corporate cash flow and debt levels are therefore also important determinants in the investment equations. Investment in intellectual property is dependent on technology spending and profits. The specification for industrial equipment investment is provided to illustrate in Table 3.

Investment in different types of nonresidential structures is driven by construction put in place, which is in turn determined by measures that proxy for absorption of space, vacancy rates, and government spending. For example, office construction put in place is determined by office-using employment, while retail construction put in place is a function of retail sales. Investment in mining structures is closely linked to changes in oil prices.

Inventory investment is divided into farm and nonfarm inventories. Nonfarm inventory change is further divided into construction and mining, manufacturing, and wholesale and retail inventories. Inventory investment is dependent on final sales and production proxied by capacity utilization. This is illustrated in Table 4.

International trade

World trade has been growing rapidly and has become more important to the U.S. economy in recent decades. This trend is expected to continue, making the international trade sector of the Moody's Analytics macroeconomic model particularly important. The Moody's Analytics macroeconomic model includes an international trade sector that captures the interactions between foreign and domestic prices, interest rates, exchange rates, and product flows.

Export prices and volumes are determined by stochastic equations, while nominal trade flows are calculated as identities. Merchandise trade flows are disaggregated between goods and services with imports of automobiles and parts also modeled.

Table 4:
Change in Private Inventories

Quarterly data from 1972:2 to 2013:1
R Bar Squared = 0.528

Dependent variable: Real changes in private inventories

	Coefficient	T-Statistic
Constant	-222.412	-4.570
Capacity utilization: Manufacturing	2.720	4.220
d(Capacity utilization: Manufacturing)	3.192	1.327
pdl(d(Final sales of domestic product),1)	0.139	3.237
pdl(d(Final sales of domestic product),2)	-0.038	-2.144

Notes: pdl(…,#) stands for a polynomial distributed lag of order #, d() stands for simple difference

Table 5:
Exports of Goods

Quarterly data from 1980:2 to 20013:1
R Bar Squared = 0.186

Dependent variable: dlog(Real exports of goods)

	Coefficient	T-Statistic
Constant	0.006	1.714
dlog(World gross domestic product)	0.456	2.501
pdl(dlog(Weighted exchange value of the dollar),1)	-0.071	-2.070

Notes: pdl(…,#) stands for a polynomial distributed lag of order #, dlog stands for simple difference of a natural logrithm

The key determinants of export volumes are global GDP growth and both the real and nominal trade-weighted value of the U.S. dollar as illustrated in Table 5 by the regression for exports of goods.

The structural equations for imports allow a richer specification than do the corresponding export equations. Real imports are determined by specific domestic spending categories and relative prices. To illustrate, Table 6 has the equation for auto imports.

Projections of international economic activity are determined using the Moody's Analytics international model system and are provided exogenously to the U.S. national and regional model system[1].

1 The term "exogenous to the U.S. model" means that it takes on values over the forecast period that have been determined elsewhere and by other means. For example, most tax rates are determined based on assumed policy changes. International economic variables, on the other hand, are determined by other forecasting models that are not run jointly with the U.S. model. Consequently, they are exogenous to the U.S. model.

Government spending and fiscal policy

Federal government policies are treated as partially exogenous in the Moody's Analytics model since legislative and administrative decisions are not predictable responses to macroeconomic conditions. Federal spending may be disaggregated in several different ways. At its most basic level, federal spending is the sum of consumption and investment expenditures. These two categories are in turn subdivided into defense and nondefense categories. Defense and nondefense consumption expenditures are each the sum of compensation and noncompensation purchases.

Total federal government outlays are the sum of defense and nondefense consumption expenditures plus transfer payments, net interest payments, subsidies less current surplus of government enterprises, federal grants-in-aid to state and local governments, less wage accruals net of disbursements. All outlays are exogenous except for transfer payments, which are a function of unemployment insurance payments, net interest payments, which are a function of interest rates and the publicly held Treasury debt, and government consumption, which is modeled as a component of GDP and assumed to grow in a trend-like manner.

Total federal government receipts are the sum of personal tax receipts, social insurance contributions, corporate profits tax receipts, and indirect tax receipts. Personal taxes account for the bulk of federal tax collections, comprising nearly one-half of total receipts. Personal tax receipts are equal to the product of the average effective income tax rate and the tax base. The tax base is defined as personal income less nontaxable components of income including other labor income and government transfers. Most average effective tax rates are exogenous and form key policy levers in the model. The personal income tax rate is modeled based on high, low and middle marginal tax rate and changes in real stock and

Table 6: Imports of Vehicles and Parts

Quarterly data from 1995:2 to 2013:1
R Bar Squared = 0.413
Durbin-Watson statistic = 2.305

Dependent variable: dlog(Real imports of vehicles and parts per person)

	Coefficient	T-Statistic
Constant	0.008	1.098
dlog(Real consumption of vehicle parts and investment in transportation equipment per person)	0.548	3.648
dlog(Ratio of import and personal consumption price deflators)	1.743	4.915
pdl(dlog(Weighted exchange value of the dollar),1)	0.090	2.440

Notes: pdl(…,#) stands for a polynomial distributed lag of order #, dlog stands for simple difference of a natural logrithm

home prices to allow more policy levers and account for capital gains tax receipts.

The federal budget deficit is measured both on a National Income and Product Accounts and on a unified basis. Differences between the two measures depend on accounting methods, coverage, and timing. For example, the unified budget counts receipts on a cash collections basis; the NIPA records corporate profit receipts on a liability basis, and personal income taxes and Social Security payments on a "when paid" basis. Unified outlays are counted when funds are disbursed while NIPA outlays are recorded at the time of delivery.

The state and local government sector of the Moody's Analytics model is modeled similarly to the federal sector. Revenues are a function of exogenous average effective tax rates and their corresponding national income categories, plus federal grants-in-aid. Expenditures for all but net interest costs are exogenously determined.

Government spending in the NIPA calculations of GDP includes government consumption and adds government investment spending. Other components are considered transfers rather than economic output. One unique feature of the government sector of the NIPA accounts is that, unlike most modeling of expenditures, government spending is forecast in nominal terms, with prices deflators forecast as well. Real values are then derived as identities.

Aggregate supply

The supply side of the Moody's Analytics macroeconomic model describes the economy's capabilities for producing output. In the Moody's Analytics model, aggregate supply or potential GDP is estimated by a Cobb-Douglas production function that combines factor input growth and improvements in productivity.

Factor inputs include labor and business fixed capital, and are defined by an estimate of the full-employment labor force and by the existing capital stock of private nonresidential equipment and structures. Population is estimated based on Census Bureau birth and death rates and immigration rates that are determined by the economic performance of the United States relative to the rest of the world. Total factor productivity is calculated as the residual from the Cobb-Douglas production function estimated at full employment. A key unknown in estimating aggregate supply is what the full employment level of labor actually is. This level is derived from a measure of potential labor supply and a measure of the long-run equilibrium unemployment rate. This rate, often referred to as NAIRU or the nonaccelerating inflation rate of unemployment, is the unemployment rate consistent with steady price (and wage) inflation. It is also the unemployment rate at which actual GDP equals potential GDP.

Estimation of the NAIRU proceeds with the estimation of an expectations augmented Phillips curve relationship between inflation and unemployment. The inflation measure used is the chain price index for personal consumption expenditures excluding food and energy. The NAIRU estimated in this Phillips curve is the married male NAIRU. This group is chosen because it is expected to have the greatest attachment to the labor market, and thus be less susceptible to changes in labor force participation than other groups that may be affected more by changing demographic composition, changed work habits, or reduced discrimination, to name several possible factors that drive labor force participation. This stability allows us to estimate a married male (MM) NAIRU that is constant over time. Married female and unmarried NAIRUs are derived via regression from the MM NAIRU. These individual NAIRUs are demographically weighted to arrive at an overall NAIRU (see Chart 1).

The growth of aggregate supply is the fundamental constraint on the long-term growth of aggregate demand. When actual GDP is above below-potential GDP, there is an output gap. Given currently high unemployment relative to NAIRU, the current output gap is large.

Inflation created by demand that approaches or surpasses potential GDP (a positive output gap) raises credit costs and weakens consumer confidence, thus constraining aggregate demand when the economy is overheating. Conversely, lower inflation and easier credit stimulate demand when economic conditions are slack. Thus, output and employment gaps form the key determinants of prices in the Moody's Analytics model, as price movements become the mechanism for restoring the full-employment level of output.

An increase in government spending, for example, narrows the output gap, driving up output prices and lowering the unemployment rate. Higher prices and a tighter labor market then force up wage rates, further igniting inflation, although this effect is partially offset by an increase in labor productivity. Higher inflation and a stronger real economy drive up interest rates and reduce real income gains. The net effect is a dampening of aggregate demand to bring it back in line with aggregate supply.

Inflation

Decisions about prices are made by individual firms. Firms adjust their prices in response to conditions in their markets. If demand has been strong and they are producing more than they think is appropriate given their current prices, they will raise their prices. If demand has been weak and they are producing less than appropriate, they will lower their prices. When we look at this process in terms of aggregate variables—GDP and the price level—prices will tend to rise whenever GDP has been above potential and will tend to fall when it has been below potential.

Firms make their price decisions with the prices of their inputs in mind. The most important input is labor. Hence, the behavior of the wage rate is a major determinant of the price adjustment process. Wages and demand pressures on prices determine a relationship between the deviation of GDP from potential and inflation. This is embodied in the wage equations of the Moody's Analytics model through an expectations-augmented Phillips curve, where wages react to expected inflation and unemployment.

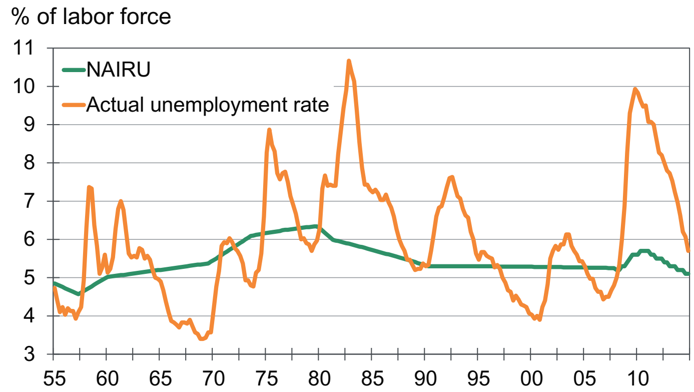
The fundamental wage equation in the model is the wage component of the Bureau of Labor Statistics' quarterly Productivity & Costs release. The explanatory variables include the difference between the actual unemployment rate and the NAIRU, private nonfarm labor productivity growth, and consumer prices. The impact of prices takes three years to fully play out as seen in Table 7.

In addition to labor, energy is another important determinant of business costs. Firms are quicker to pass through energy price increases to consumers on goods that are especially sensitive to oil prices such as gasoline and agricultural commodities. Firms also pass through price increases on services such as airfare, train fare and wholesale trade after material and persistent rises in their energy costs. Electricity and natural gas consumer prices are slower to rise, since utilities must seek the permission of policymakers in order to raise prices in the regulated utilities industry. Energy is an input cost to virtually every firm in every industry. As such, rising energy prices boost the prices for all goods and services to the extent that firms pass through price increases.

More than 60 producer price index components are forecast in the model. Most are forecast based on historical performance relative to demand and other relevant drivers. More aggregate producer price indexes are determined by a weighted average of other producer prices and labor costs. The weights reflect the composition of each producer price's factor inputs.

The consumer price indexes in the Moody's Analytics model are driven by producer prices, labor costs, and import prices. Import price deflators, for example, are direct determinants of many of the indexes for consumption goods. The core components of consumer prices are determined by the appropriate price deflators. Oil and food prices are determined exogenously. Consumer ex-

Chart 1: Great Recession Took Toll on Job Market



Sources: BLS, Moody's Analytics

Table 7: Nonfarm Hourly Compensation

Quarterly data from 1957:1 to 2013:1
R Bar Squared = 0.375

Dependent variable: dlog(Nonfarm hourly compensation)

	Coefficient	T-Statistic
20-qtr MA(Unemployment rate less NAIRU, lag 1)	-0.001	-2.542
dlog(12-qtr MA(Nonfarm output per hour, lag 1))	0.789	8.491
pdl(dlog(Price index: Personal consumption expenditures, lag 1), 1)	0.151	6.950
pdl(dlog(Price index: Personal consumption expenditures, lag 1), 2)	-0.032	-2.133

Notes: pdl(…,#) stands for a polynomial distributed lag of order #, dlog stands for simple difference of a natural logrithm

Table 8: Intermediate Estimate for Federal Funds Rate

Quarterly data from 1979:1 to 2014:4
R Bar Squared = 0.959
Durbin-Watson statistic = 1.67

Dependent variable: Intermediate estimate: Federal funds rate

	Coefficient	T-Statistic
pchy(40-qtr MA(Nominal potential GDP))	0.258	4.917
Core PCE inflation, 4-qtr MA, less Fed inflation target	0.430	5.086
Unemployment rate less NAIRU	-0.203	-3.734
Stock market volatility, 2-qtr MA	-0.270	-1.567
Federal funds rate, lag 1	0.752	16.894

Notes: pchy stands for % change yr ago

penditure deflators are primarily determined by related consumer price indexes, although in some cases more fundamental drivers are utilized. The aggregate PCE deflator is determined stochastically and component deflators are constrained to be consistent.

Monetary policy and financial markets

The key short-term rate in the Moody's Analytics model is the federal funds rate. The funds rate equation was estimated beginning when Paul Volker became chairman of the Federal Reserve Board in 1979. This period includes a number of very different approaches to the conduct of monetary policy, including Volker's implementation of monetarist theories, Alan Greenspan's policy of opportunistic disinflation, and Ben Bernanke's use of unconventional monetary policy tools to combat the Great Recession and financial crisis.

Despite the differences in approach, monetary policy as represented by the federal funds rate is best modeled with a Taylor rule specification. Developed by Stanford economist John Taylor, the Taylor rule has been used as an important reference point for policymakers as they craft monetary policy as the economy changes. The Taylor rule is a central bank reaction function that computes an optimal federal funds rate from the equilibrium funds rate—that rate consistent with an economy operating at full-employment, growing at its potential with inflation at the Fed's target—and deviations of inflation from the Fed's target, and economic output from its potential. Stock market volatility is also included in the reaction function to proxy for the impact of financial market stress on policymakers' views of the appropriate funds rate target.

When the economy is operating at full employment and inflation is at the rate consistent with the Fed's definition of price stability, the federal funds rate should be equal to its equilibrium rate.The Taylor rule prescribes the central bank to lower interest rates when either inflation or the economy is operating below its respective target, and vice versa.

The Taylor rule has done a reasonably good job in tracking actions by the FOMC since the late 1970s. As the Taylor rule was vetted by accurately predicting Fed actions, it provided financial markets a good metric to ascertain the path of monetary policy. For much of the period after the Great Recession, the Taylor rule called for a negative federal funds rate. Since that is extremely unlikely in reality and creates problems for the model, a minimum, positive rate is imposed. The equation is shown in Table 8.

A theoretical negative funds rate does eventually result in quantitative easing by the Fed in the model. The amount of QE that is predicted by the model is conditioned off of the experience with three rounds of QE during and in the wake of the Great Recession.

The yield on the 10-year Treasury bond is the key long-term interest rate in the model system. The yield is modeled as a function of those factors generally followed by bond investors, including the path of FOMC policy as indicated by the federal funds rate, inflation expectations, and three variables that influence the size of the term premium—the Treasury debt-to-GDP ratio, excess reserves, which proxy for quantitative easing, and stock market volatility, which captures the flight-to-quality to Treasury bonds in times of financial market and geo-political stress. Table 9 shows the equation for the 10-year Treasury yield.

The federal funds rates and 10-year Treasury yield rates serve as the foundation for all interest rate forecasts in the model. Others are forecast as spreads from these rates, which are driven by appropriate drivers. For example, corporate bond yield spreads are driven by corporate profits and corporate interest payments. Municipal interest rates, an expanded section of the model, are similarly specified.

Turning to the remainder of the financial sector, money demand equations are derived from portfolio theory; the demand for cash depends on the level of income, the expected level of transactions, and the opportunity cost of holding liquid assets as opposed to other interest-earning instruments. Money is not a single asset, but rather a group of asset categories with varying degrees of liquidity. At one extreme is currency, which can be exchanged directly for assets; money also includes savings and time accounts, and, at the other extreme, certificates of deposit.

Required reserves—determined by the components of money demand and the monetary policy lever specifying the required ratio—define the demand for reserves in the banking system. Free reserves, defined as nonborrowed

Table 9:
10-Year Treasury Yield

Quarterly data from 1979:1 to 2014:4
R Bar Squared = 0.976
Durbin-Watson stat = 1.515

Dependent variable: 10-Yr treasury yield

	Coefficient	T-Statistic
Federal funds rate	0.159	6.229
Stock market volatility	-0.089	-1.157
Publicly held debt as share of GDP lag 1, 2-qtr MA	0.010	3.100
Total reserves as share of GDP lag 1, 4-qtr MA	-0.019	-1.024
10-Year Treasury yield lag 1	0.822	27.010

Notes: pchy stands for % change yr ago

reserves less required reserves, are a measure of disequilibrium. Total, borrowed and excess reserves are included for completeness.

Personal income and corporate profits

While the income side of the NIPA accounts is not as carefully followed as the demand side of the accounts, it is the income sector that makes macroeconomic models truly general equilibrium models. One household's spending is income to another household, while income generated by production is a constraint on final demand. Moreover, the distribution of income among households, businesses, and government has significant effects on the composition of output and on the dynamics of the business cycle.

National income is defined as the sum of the payments to the factors of production. The Moody's Analytics Macro Model has behavioral equations for all nonprofit income flows including compensation of employees (wages and benefits), other labor income, employer contributions for social insurance, farm and nonfarm proprietors' income, and net interest paid by business.

Corporate profits with inventory valuation adjustment and capital consumption adjustment are estimated by a regression on output, labor costs and prices as shown in Table 10.

Corporate cash flow is determined by subtracting dividends and corporate taxes from corporate profits and adding depreciation allowances. A key stock price variable in the U.S. Macro Model has been the S&P 500 Composite Stock Price Index. This is modeled as a function of after-tax profits, stock price volatility, and a distributed lag on the 10-year government bond rate. A new variable, the Dow Jones total stock market index, has been added to the model in order to meet Comprehensive Capital Analysis and Review reporting requirements. Over history, the two series have shown very similar behavior. Consequently, the S&P variable is the primary driver for the Dow Jones index.

Labor market

The labor market sector determines payroll employment, household employment, the labor force, the number of unemployed, and the rate of unemployment.

Private payroll employment is modeled from both a top-down and bottom-up approach. Total private employment is derived as a function of labor hours demanded, which in turn is a function of output. Labor hours

Table 10:
Corporate Profits With Inventory Valuation and Capital Consumption Adjustments

Quarterly data from 1970:1 to 2013:2
R Bar Squared = 0.953
Durbin-Watson statistic = 1.843

Dependent variable: log(Ratio of corporate profits to nomimal gross domestic product)

	Coefficient	T-Statistic
log(8-qtr MA(Ratio of gross domestic product price index and unit labor cost index, lag 1))	4.671	11.975
log(4-qtr MA(Crude materials producer price index))	-0.406	-36.696
Dummy variable for 2008:1	-0.219	-8.193
pdl(dlog(Real gross domestic product), 1)	2.135	8.553
Error correction residual, lag 1	0.922	30.694

Notes: pdl(…,#) stands for a polynomial distributed lag of order #, log stands for natural logarithm

Table 11:
Aggregate Hours Worked: Total Private Sector

Quarterly data from 1952:1 to 2013:1
R Bar Squared = 0.999
Durbin-Watson statistic = 1.961

Dependent variable: log(Aggregate hrs worked: Total private sector)

	Coefficient	T-Statistic
Constant	4.446	55.484
log(Nonfarm business output index, lag 1)	0.947	38.232
log(Nonfarm business output per hr index, lag 1)	-0.912	-21.669
Error correction residual, lag 1	0.688	11.336

Notes: log stands for natural logrithm

Table 12:
Intermediate Estimate of Construction Industry (NAICS 23) Employment

Quarterly data from 1977:2 to 2013:1
R Bar Squared = 0.673

Dependent variable: dlog(Intermediate estimate: Construction industry employment)

	Coefficient	T-Statistic
Constant	0.005	4.842
dlog(Gross product: Construction)	0.743	17.214
dlog(1-qtr MA(Nonfarm business output per hr index))	-0.609	-5.236

Notes: dlog stands for simple difference of a natural logarithm

are modeled based on lagged growth in output and labor productivity as seen in Table 11.

Payroll employment is also modeled separately at the one-digit and two-digit NAICS level. To properly examine industry-specific employment impacts attributed to changes in consumer spending, business investment, trade and federal and state government spending, Moody's Analytics has incorporated data from the 1997 benchmark of the Bureau of Economic Analysis' U.S. Input-Output Accounts. These data are used to generate quarterly estimates of gross product originating by industry as follows:

GPO by industry = the industry's share of total consumption*Real personal consumption expenditures + the industry's share of investment*Real investment + the industry's share of exports*Real exports + the industry's share of imports*Real imports +the industry's share of federal spending*Real federal gross investment and consumption + the industry's share of state and local spending*Real state and local gross investment and consumption.

Industry payroll employment depends on the industry specific gross product originating and productivity terms in some cases as illustrated in Table 12 for construction employment.

This intermediate value of construction employment is then divided by the sum of all the intermediate estimates of employment categories. This share is then applied to total private employment estimated separately. Thus, relative industry employment shifts occur, even though the actual industry employment levels are squeezed to equal the change in top-line private employment.

Household employment is modeled as a function of total payroll employment. The two measures of employment can vary over the business cycle given changes in the number of people holding multiple jobs and the number of self-employed. These differences should be captured in the national level variable.

The labor force is determined by the working age population, real hourly compensation and the share of the population of prime working age. The equation is shown in Table 13. The rate of labor force participation is determined through an identity.

The number of unemployed and the unemployment rate are determined as identities from the household employment and labor force projections.

Personal income

The personal income sector is composed of eight different components. Wages and salaries, the largest income category, are divided into manufacturing, private service producing, and construction and mining categories. In the same spirit as employment,

Table 13:
Labor Force

Quarterly data from 1985:1 to 2013:1
R Bar Squared = 0.989
Durbin-Watson statistic = 0.095

Dependent variable: log(Labor Force)

	Coefficient	T-Statistic
log(Population)	0.557	14.762
log(4-qtr MA(Ratio of hourly compensation to core prices, lag 1))	0.417	9.787
log(Share of population ages 25 to 54)	0.603	9.557

Notes: log stands for natural logarithm

Table 14:
Intermediate Estimate for Income: Wages and Salaries

Quarterly data from 1995:1 to 2013:1
R Bar Squared = 0.454

Dependent variable: dlog(Income: Private wages and salaries)

	Coefficient	T-Statistic
dlog(Total private nonfarm avg weekly earnings)	1.129	11.987

Notes: dlog stands for simple difference of a natural logarithm

Table 15:
Intermediate Estimate for Income: Wages and Salaries, Wholesale Trade

Quarterly data from 1995:1 to 2013:1
R Bar Squared = 0.515

Dependent variable: dlog(Income: Wages and salaries, wholesale trade)

	Coefficient	T-Statistic
dlog(Avg weekly earnings: Wholesale trade)	1.161	13.325

Notes: dlog stands for simple difference of a natural logarithm

wages and salaries are modeled from a top-down and bottom-up approach.

Table 14 shows how total wages and salaries are modeled as a function of average weekly earnings. Individual wage and salary categories are modeled as a function of industry employment, industry average hourly earnings, and a broad measure of hours worked. Table 15 is an example using NAICS category 42, wholesale trade.

This intermediate value of wholesale trade payroll employment is then divided by the sum of all the intermediate estimates of wage and salary categories. This share is then applied to total wages and salaries estimated earlier. Thus, once again, relative industry employment and wage changes change the share of total wages going to any one industry, thus accounting for shifts in relative productivities.

Moving past wages and salaries to other income categories, supplements to wages and salaries, basically benefits, are estimated as a function of wages and salaries. The sizable constant term reflects the rapid growth in this category of income over the past two decades due to rising medical costs and nonwage benefits. Contributions for social insurance are also a function of wages and salaries and tax rates.

Interest income is estimated from a regression on a weighted average of short- and long-term interest rates. Dividend income is a function of corporate dividend payments. Rental income is exogenous. Proprietors' income is derived from output and profits, while transfer payments are a function primarily of the share of the population over 65 since Social Security benefits are the largest component. The unemployment rate and the rate of consumer price inflation also play a role.

Housing

The housing sector determines the number of single-family and multifamily housing permits, starts, completions, new- and existing-home sales, house prices, mortgage originations for purchase and refinancing, and mortgage delinquency and foreclosure rates. Over the long run, demographic factors such as household formation and income growth drive growth of the housing market. Business cycles and construction cycles, as represented by the jobless rate and the availability and cost of labor and building materials, will create disequilibrium between housing demand and supply in the short run. The Moody's Analytics model of housing measures includes both these long-term and short-term forces.

For example, the demand for homes as expressed by new- and existing-home sales is related to household formation over the long term. Real per household income growth is also an important determinant of housing demand as higher incomes make it possible for more households to buy a home. The user cost of housing, or the after tax interest cost of owning a home less the expected return to buying a home, is a short-term driver of home sales. The higher the user cost, the lower home sales. The expected return to buying a home is expected house price appreciation. The home sales equations also include a measure of credit availability: Looser lending standards help drive sales in the near term.

Similarly, the level of housing permits issued is largely determined by the number of household formations over the long term. Over time, the level of housing permits issued will closely follow the number of new household formations, abstracting from demolitions. Permits and household formations are not equal in each period, however, given changes in the business cycle and building activity. Also affecting starts and sales therefore are general economic conditions as represented by employment or income growth, the user cost of housing, and the availability of credit. Credit availability has become a particularly important factor influencing the level of home building given recent changes in bank capital standards and the emphasis of bank regulators on credit quality. In the Moody's Analytics model, single-family housing permits are modeled as shown in Table 16.

House prices are specified as a function of factors that influence both the demand and supply of homes (see Table 17). The demand for homes depends on income per household, the jobless rate, after-tax borrowing costs, credit availability, and the distress sale share of total existing-home sales. Income per household measures both the ability and willingness of households to purchase a home. Rising income levels will result in increased home buying activity. The jobless rate also impacts consumers' willingness to buy. If consumer confidence is low, home buying will remain lackluster even if income levels are growing. Finally, the distress sale share of total existing-home sales has had a significant impact on house prices during the recent housing boom-bust cycle, representing discounted excess supply of housing. House price appreciation and changes in the distress share are inversely correlated. As such, the distress share is also included as an explanatory variable in the house price model.

Purchase mortgage originations are modeled as a function of the value of new- and existing-home sales and the loan-to-value ratio. To account for the changing share of home sales that are for cash, the mortgage foreclosure rate is included in the equation. The cash share of home sales tends to be greater when there are more distress sales that are purchased by investors with cash. Refinance originations as a share of mortgage debt outstanding are determined by the difference between the current 30-year fixed mortgage interest rate and the average rate over the last five years (the average duration of a mortgage loan). The spread between interest rates on fixed and adjustable rate mortgages is also included in the model to capture the desire of ARM borrowers to

Table 16: Single-Family Permits

Quarterly data from 1984:1 to 2010:2
R Bar Squared = 0.79
Durbin-Watson statistic = 0.422

Dependent variable: log(Single-family permits per household)

	Coefficient	T-Statistic
30-yr fixed mortage rate adjusted for persoanl income taxes less pcy(4-qtr MA(Median single-family existing-home price, lag 1))	-0.043	-13.052
Spread between 30-yr fixed and 30-yr adjustable mortgage rates	0.114	5.321
Loan to price ratio	-0.064	-93.596
pdl(dlog(Real disposable income per household), 1)	7.564	8.701
pdl(dlog(Real disposable income per household), 2)	-0.558	-2.563

Notes: pcy stands for % change yr ago, pdl(…,#) stands for a polynomial distributed lag of order #, dlog stands for simple difference of a natural logrithm, log stands for natural logrithm

Table 17: FHFA Purchase-Only Home Price Index

Quarterly data from 1991:2 to 2008:3
R Bar Squared = 0.257
Durbin-Watson statistic = 0.378

Dependent variable: dlog(Purchase only home price index)

	Coefficient	T-Statistic
dlog(4-qtr MA(Nominal disposable income per household))	1.028	8.493
dlog(4-qtr MA(30-yr fixed mortage rate adjusted for persoanl income taxes))	-0.199	-3.214
dlog(4-qtr MA(Unemployment rate))	-0.062	-1.473
dlog(4-qtr MA(.75 multiplied by share of loans with adjustable rate plus .25 multiplied by loan to price value))	0.090	3.598
d(Share of distressed home sales)	-0.004	-3.578

Notes: dlog stands for simple difference of a natural logarithm, d() stands for simple difference

refinance and lock in fixed rates when those rates are low.

Mortgage delinquency rates are determined by employment growth, house price changes, household financial obligations, and loan-to-value ratios. Employment growth reflects the ability of homeowners to meet their mortgage payments, while the change in house prices captures changes in the level of homeowners' equity. Significant declines in equity values are necessary before homeowners will stop making their mortgage payments altogether. Mortgage foreclosures are modeled as a function of lagged mortgage delinquencies, real house price movements, household financial obligations, and employment growth.

The housing sector has been expanded substantially since the housing boom and bust. Some notable additions to this part of the model include the CoreLogic Case-Shiller® 20-City Single-Family Home Price Index, single-family months of supply at current sales rate, and new single-family homes for sale.

Consumer sector

The consumer sector includes retail sales, the consumer balance sheet including consumer credit outstanding, the consumer credit delinquency rate, debt burden and obligations, the consumer price index, and household cash flow. Consumer credit outstanding is modeled based on consumer spending, income growth, short-term interest rates, and mortgage refinancing activity. Homeownership and house prices are drivers of housing assets.

The consumer credit delinquency rate depends on the jobless rate, personal income growth, financial obligations, lending standards, and house price growth. Each of these explanatory variables affects the ability of households to meet their debt obligations. Financial obligations are a function of the level of debt relative to income by type and interest rates. Household cash flow is a function of house price growth, movements in the stock market, consumer confidence which impacts consumers' desire to borrow, realized capital gains, and interest rates.

Industry detail

The U.S. Macro Model uses gross product originating data to capture the interindustsry detail in the economy. The empirical approach to link final demand aggregates to current estimates of GPO. Fifteen industry grouping models are estimated as Bayesian vector autoregression models. By design, his is a purely data-dependent approach. Each model explains the behavior of both real output and the corresponding implicit price deflators for a small group of industries. Real GPO is expressed on a per capita basis, while the deflators are all modeled relative to the overall GDP deflator. The exogenous variables on the right hand side of each and every equation are virtually identical for all 15 models and are present in order to provide a data-based mapping between final demand components and the GPO variables. In each equation, lagged values of all the endogenous variables appear as well. The goal model provides reasonable forecasts and exhibits stability in the face of shocks in final demand.

Model maintenance

Moody's Analytics views the model as a tool to be constantly refined and enhanced. While we do a formal forecast accuracy evaluation each spring, which is documented in our Regional Financial Review publication, we evaluate the performance of the model on an ongoing basis. Rarely does a month go by when no changes are made to the model. Equations that are no longer performing well are respecified, and variables are occasionally added to the model as more data become available or the dynamics of the economy change. These are identified both by the team of economists that is assisting with the monthly forecast process and questions from clients. Despite this, we find that some relationships stand the test of time and do not respecify or even re-estimate equations that are performing well.

About the Author

Mark Zandi

Mark M. Zandi is chief economist of Moody's Analytics, where he directs economic research. Moody's Analytics, a subsidiary of Moody's Corp., is a leading provider of economic research, data and analytical tools. Dr. Zandi is a cofounder of Economy.com, which Moody's purchased in 2005.

Dr. Zandi's broad research interests encompass macroeconomics, financial markets and public policy. His recent research has focused on mortgage finance reform and the determinants of mortgage foreclosure and personal bankruptcy. He has analyzed the economic impact of various tax and government spending policies and assessed the appropriate monetary policy response to bubbles in asset markets.

A trusted adviser to policymakers and an influential source of economic analysis for businesses, journalists and the public, Dr. Zandi frequently testifies before Congress on topics including the economic outlook, the nation's daunting fiscal challenges, the merits of fiscal stimulus, financial regulatory reform, and foreclosure mitigation.

Dr. Zandi conducts regular briefings on the economy for corporate boards, trade associations and policymakers at all levels. He is on the board of directors of MGIC, the nation's largest private mortgage insurance company, and The Reinvestment Fund, a large CDFI that makes investments in disadvantaged neighborhoods. He is often quoted in national and global publications and interviewed by major news media outlets, and is a frequent guest on CNBC, NPR, Meet the Press, CNN, and various other national networks and news programs.

Dr. Zandi is the author of Paying the Price: Ending the Great Recession and Beginning a New American Century, which provides an assessment of the monetary and fiscal policy response to the Great Recession. His other book, Financial Shock: A 360º Look at the Subprime Mortgage Implosion, and How to Avoid the Next Financial Crisis, is described by the New York Times as the "clearest guide" to the financial crisis.

Dr. Zandi earned his BS from the Wharton School at the University of Pennsylvania and his PhD at the University of Pennsylvania. He lives with his wife and three children in the suburbs of Philadelphia.

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About Moody's Analytics
Economic & Consumer Credit Analytics

Moody's Analytics helps capital markets and credit risk management professionals worldwide respond to an evolving marketplace with confidence. Through its team of economists, Moody's Analytics is a leading independent provider of data, analysis, modeling and forecasts on national and regional economies, financial markets, and credit risk.

Moody's Analytics tracks and analyzes trends in consumer credit and spending, output and income, mortgage activity, population, central bank behavior, and prices. Our customized models, concise and timely reports, and one of the largest assembled financial, economic and demographic databases support firms and policymakers in strategic planning, product and sales forecasting, credit risk and sensitivity management, and investment research. Our customers include multinational corporations, governments at all levels, central banks and financial regulators, retailers, mutual funds, financial institutions, utilities, residential and commercial real estate firms, insurance companies, and professional investors.

Our web periodicals and special publications cover every U.S. state and metropolitan area; countries throughout Europe, Asia and the Americas; the world's major cities; and the U.S. housing market and other industries. From our offices in the U.S., the United Kingdom, the Czech Republic and Australia, we provide up-to-the-minute reporting and analysis on the world's major economies.

Moody's Analytics added Economy.com to its portfolio in 2005. Now called Economic & Consumer Credit Analytics, this arm is based in West Chester PA, a suburb of Philadelphia, with offices in London, Prague and Sydney. More information is available at www.economy.com.

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