RBC Methodology and the Development of Aggregate Economic Theory

Edward C. Prescott
Arizona State University
and Federal Reserve Bank of Minneapolis

Staff Report 527
February 2016

Keywords: Neoclassical growth theory; Aggregate economic theory; RBC methodology; Aggregation; Business cycle fluctuations; Development; Aggregate financial economics; Prosperities; Depressions

JEL classification: B4, C10, E00, E13, E32, E60

Federal Reserve Bank of Minneapolis • 90 Hennepin Avenue • Minneapolis, MN 55480-0291
https://www.minneapolisfed.org/research/

RBC Methodology and the Development of Aggregate Economic Theory

Edward C. Prescott

Summary

This essay reviews the development of neoclassical growth theory, a unified theory of aggregate economic phenomena that was first used to study business cycles and aggregate labor supply. Subsequently, the theory has been used to understand asset pricing, growth miracles and disasters, monetary economics, capital accounts, aggregate public finance, economic development, and foreign direct investment.

The focus of this essay is on real business cycle (RBC) methodology. Those who employ the discipline behind the methodology to address various quantitative questions come up with essentially the same answer—evidence that the theory has a life of its own, directing researchers to essentially the same conclusions when they apply its discipline. Deviations from the theory sometimes arise and remain open for a considerable period before they are resolved by better measurement and extensions of the theory. Elements of the discipline include selecting a model economy or sometimes a set of model economies. The model used to address a specific question or issue must have a consistent set of national accounts with all the accounting identities holding. In addition, the model assumptions must be consistent across applications and be consistent with micro as well as aggregate observations. Reality is complex, and any model economy used is necessarily an abstraction and therefore false. This does not mean, however, that model economies are not useful in drawing scientific inference.

The vast number of contributions made by many researchers who have used this methodology precludes reviewing them all in this essay. Instead, the contributions reviewed here are ones that illustrate methodological points or extend the applicability of neoclassical growth theory. Of particular interest will be important developments subsequent to the Cooley (1995) volume, *Frontiers of Business Cycle Research*. The interaction between theory and measurement is emphasized because this is the way in which hard quantitative sciences progress.

Keywords: Neoclassical growth theory, aggregate economic theory, RBC methodology, aggregation, business cycle fluctuations, development, aggregate financial economics, prosperities, depressions

JEL Codes: B4; C10; E00; E13; E32; E60

Section 1: Introduction

This chapter reviews the development and use of a quantitative, unified theory of aggregate variables both across time and across economies at a point in time. This theory accounts not only for traditional business cycle fluctuations but also for prosperities and depressions, as well as the vast difference in living standards across countries. This unified quantitative dynamic general equilibrium theory accounts for the large movements in asset values relative to gross national income, the consequences of alternative monetary policies and tax systems, and the behavior of current accounts as well.

No competing quantitative theory has been developed for the study of aggregate economic behavior. This disciplined theory is unified and has been tested through successful use. The assumptions made when constructing a model economy, or in some cases a set of economies, to address a given question must be consistent with assumptions made in the previous successful applications. Deviations from this theory have arisen, which is evidence that some real theory is involved.[1] Other deviations remain to be discovered. Some of the recognized deviations or puzzles have been resolved via further development of the theory, others by better measurement. This interaction between theory and measurement is the way in which a hard quantitative science progresses.

We call this theory neoclassical growth theory. Key features of this theory are the allocation of productive time between market and household activities and the allocation of output between consumption and investment. Depending on the application, other features of reality must be included, such as sector detail, the nature of the financial system as specified by laws and regulations, and the contracting technology available. Heterogeneity of people in the model economy, with respect to age and idiosyncratic shocks, must be and has been included in models used to address issues such as the consequences of an aging population for various tax policy regimes.

The underlying theoretical framework is the theory of value, in particular the capital theory variant. This means the models used to draw scientific inference will have a recursive structure. This is a crucial feature for the model economies being used to draw scientific inference because the national account statistics can be constructed and compared with actual statistics.

[1] Trade theory is a disciplined theory. All using the discipline of trade theory come up with essentially the same findings. See Arkolakis, Costinot, and Rodríquez-Clare (2012).

To summarize, aggregate economics is now a hard quantitative science. It has been tested through successful use in all substantive fields of economics.

Section 2: A Brief History of Business Cycles

Fluctuations in the level of business activity have long been a topic of concern. Wesley Mitchell (1913, 1927) collected many indicators of the level of economic activity. He viewed the level of economic activity as being cyclical with alternating periods of contractions and expansions. He developed the National Bureau of Economic Research (NBER) definition of recession, which is a period of contraction in the level of economic activity. This definition is still used by the NBER. He categorized his set of indicators into leading indicators, lagging indicators, and contemporaneous indicators. This was the framework he used for forecasting, and it did improve forecasting.

Mitchell called these fluctuations "business cycles." Wicksell (1918) used a rocking horse analogy to think about business cycles. Rocking horses display damped oscillations absent new shocks. This development led the profession to search for an economic structure with these properties. Ragnar Frisch (1933) viewed business cycle research as the search for shocks or impulses to the economy and a damped oscillatory propagation mechanism.

Samuelson (1939) developed his multiplier-accelerator macroeconomic model that displayed these properties. His model had a consumption function and an investment equation. His model was also a second-order linear equation in real output with parameters that gave rise to damped oscillatory behavior.

The NBER definition of recessions is flawed along three dimensions. First, no corrections are made for trend growth or population size. With the NBER definition, the economy is in expansion 90 percent of the time and in recession or contraction 10 percent of the time. With trend-corrected real gross domestic product (GDP) per person 16 years and older, the economy is expanding approximately half of the time and contracting half of the time. Second, the NBER definition of recession is not revised subsequent to revisions in the economic time series. These revisions are sometimes large and are made years later as recent census data become available. If the revised data were used, the timing and magnitude of recessions and expansions would change. Third, the NBER definition of recession is not well defined and has a large subjective element.

The biggest problem in business cycle theory is that these so-called business cycles are not cyclical. This was established by Adelman and Adelman (1959), who found that the Klein-Goldberg model—the first econometric model to be used to forecast business cycles—displays damped non-oscillatory behavior. This finding, however, does not rule out the existence of longer cycles in the level of business activity.

Kuznets's (1930) view was that there were 15- to 20-year cycles in output and prices in the United States. He labeled these fluctuations "secondary secular movements." Subsequently, they were called Kuznets cycles. Kondratieff (1935) hypothesized even longer business fluctuations with 50- to 60-year cycles.

There are, of course, seasonal cycles, which are cycles in the true sense of the word. But they are of little interest and receive little attention in aggregate analysis. To handle them, the economic data used in aggregate analyses are seasonally adjusted.

2.1 The National Accounts: Defining Macroeconomics

A goal in the early 1930s was to come up with a measure of the performance of the business sector. Simon Kuznets (1930) came up with one that proved to be useful. This measure is gross national product (GNP), the value of all final goods and services produced. Other researchers measured the value of the inputs to the business sector, which are the services of capital stocks. The most important category of these services is the services of different types of human capital. The aggregate value of human capital services is commonly called labor income. The services of tangible capital make up the other major category. The aggregate value of these services is called capital income. Claims against output are by definition income, and given that all businesses have a residual claimant, income equals product.

In the late 1930s, Jan Tinbergen (1952) developed quantitative dynamic time series models and used them for forecasting. Given his background in physics, he thought in terms of empirically determined dynamic systems with instruments and targets.

On the other hand, Lawrence R. Klein, the father of macroeconometric modeling, had a theory underlying the dynamic aggregate models he developed and used for forecasting. The theory is the Hicksian IS-LM theory, later augmented with a Phillips curve. The beauty of Klein's work was that it featured a fully specified dynamic system, which had national accounts. All accounting identities held, which resulted in a consistent set of forecasts for all of the variables. Over time, these macroeconometric models grew in size as the sector detail became richer. Klein's model and other macroeconometric models in his framework came to dominate because their use dramatically improved forecasting. After World War II, for example, most economists thought the United States would

experience another Great Depression. Using his model, Klein correctly forecasted that no depression would occur.

The nature of macroeconomics in the 1960s was coming up with a better equation to be included in the basic macroeconomic model. The generally held view was that the neoclassical foundations for the empirically determined aggregate dynamic system would subsequently be developed. The famous Phelps Conference at the University of Pennsylvania in 1969, entitled "Micro Foundations of Wage and Price Determination," tried to bring about the synthesis of macroeconometric models into neoclassical economics.

This neoclassical synthesis, however, was not to be. Lucas (1976a), in his paper entitled "Econometric Policy Evaluation: A Critique," found that the existence of a policy-invariant dynamic system is inconsistent with dynamic economic theory. The implication of this finding was that there was no hope for the neoclassical synthesis. The use of dynamic economic theory to evaluate policy requires that the dynamic system governing the evolution of the national accounts be an endogenous element and not a policy-invariant element, which can be empirically determined.

What happens at a point in time depends on what policy regime will be followed in the future. An implication of this fact is that economic theory cannot predict what will happen as a consequence of a possible current policy action choice. What will happen as the result of a policy action is not a well-posed question in the language of dynamic economic theory. What will happen if some policy rule or regime is followed in the future is a well-posed economic question—a point made by Robert Lucas (1976a).

No one challenged Lucas's conclusions, and those who continued to support the use of macroeconometric models for evaluating policy took the position that a different theoretical framework was needed for the study of business cycle fluctuations. Indeed, many used the theory underlying macroeconometric models of the 1960s to confidently predict that the unemployment rate could be decreased by increasing the inflation rate. In 1969 the unemployment rate and inflation rate were both about 4 percent. The policy consensus based on the perceived trade-off between inflation and unemployment was that the unemployment rate should be reduced, because the social gains from having a lower unemployment rate exceeded the cost of the higher inflation.

This consensus led to an attempt to exploit this trade-off in the 1970s. As Lucas and Sargent (1979) point out, this attempt failed—and failed spectacularly, as predicted by dynamic economic theory.[2] Given this failure of Keynesian macroeconomics, the question was what would replace it.

[2] Lucas (1972), in what was probably the first dynamic aggregate theory paper, developed a model that displayed an empirical Phillips curve. He predicted that if attempts were made to exploit, they would fail. This prediction was made prior to the attempts to lower the unemployment rate by increasing the inflation rate.

2.2 Neoclassical Growth Theory: The Theory Used in Aggregate Analysis

The development of aggregate measures of outputs and inputs to the business accounts led to the identification of a set of growth facts. Kaldor's (1957) stylized view of these facts for long-term economic growth in the United States and the United Kingdom are as follows. Roughly constant are capital and labor shares of national income, consumption and investment shares of output, the return on investment, and the capital-output ratio. Growing at the same rate over time are national income and the real wage.

Solow (1956) developed a simple, elegant model that accounted for these facts. The model has an aggregate production function with constant returns to scale, with labor and capital being paid their marginal product. All productivity change is labor augmenting. Investment is a constant share of output, and the time allocated to market production per worker is a constant. Thus, the household makes no decisions. Following Frisch (1970), I therefore refer to the model as being classical.

Around the same time, Swan (1956) developed his growth model that is also consistent with the Kaldor growth facts. The key difference between his model and Solow's model is that Swan did not require neutral technology change. Instead, he assumed a unit elasticity of substitution between the factors of production. In the Swan (1956) paper, he carries out some output accounting. The Swan model is the one that has been used for output accounting.

2.3 The Classical Growth Model and Business Cycle Fluctuations

Lucas (1976b) defined business cycles as being recurrent fluctuations of output and employment about trend and the key facts to be the nature of co-movements of aggregate variables about trend. But without a definition of trend, this is not a fully specified definition of business cycle fluctuations. This led Hodrick and Prescott (1980) to develop an operational definition of trend, and they used it to represent time series as the sum of a trend component and a business cycle component. In constructing the trend, a penalty was imposed on the sum of squares of the second differences of the trend. In mathematical terms, a time series y_t is represented as the sum of a trend component g_t and a cyclical component c_t; that is,

$$y_t = g_t + c_t .$$

Given the values of the y_t, the g_t are selected to minimize

$$\sum_{t=1}^{T} c_t^2 + \lambda \sum_{t=-1}^{T} [(g_t - g_{t-1}) - (g_{t-1} - g_{t-2})]^2 .$$

This simple operational procedure has a single smoothing parameter, $\lambda \geq 0$. This parameter is chosen to mimic the smooth curve researchers would draw through the data. The larger its value, the smoother is the trend component. For quarterly data, the first number that Hodrick and I chose and ended up using was 1600. There is no right or wrong number, and it cannot be estimated because it is part of an operational definition. What is desirable is that the same statistics are used across studies of business cycle fluctuations of this type. This uniformity permits comparisons across studies.

A feature of this procedure is that the same linear transformation of the logarithm of all the inputs and outputs to the business sector is made. Consequently, Swan's (1956) output accounting could be used for the operationally defined cyclical component of the time series.

In examining the nature of these fluctuations, researchers documented some business cycle facts for the deviations from trend for the U.S. economy for the 1950.1 to 1979.2 period:

(i) Consumption, investment, market hours, and labor productivity all moved procyclically.
(ii) The standard deviation of fixed investment was 5.1 percent, and the standard deviation of consumption was only 1.3 percent.
(iii) Market hours and GDP per hour were roughly orthogonal, with hours having twice the variance.
(iv) The standard deviation of quarterly log output was 1.8 percent, and the first-order serial correlation was 0.74.
(v) Stocks of capital lagged output, with the lag increasing with the durability of the capital. Inventory stock was almost contemporaneous, producer durables stocks lagged a few quarters, and structures lagged a couple of years.

2.4 The Neoclassical Growth Model

Kydland and Prescott (1982) added an aggregate household to the classical growth model in order to endogenize two key allocation decisions. The first of these allocation decisions is the split of output between investment and consumption. The split varies cyclically. The second of these allocation decisions is how much productive time is allocated to the business sector and how much to the household sector. These allocations are endogenous elements of the neoclassical growth model and, with respect to the aggregate household, depend on both its willingness and its ability to substitute. Thus, this extension of the growth model made it neoclassical in the sense of Frisch (1970).

Kydland and I found that if there were persistent shocks to factors determining the balanced growth path *level* of the neoclassical growth model and if the aggregate household was sufficiently willing to intertemporally substitute market time, the neoclassical growth model displayed fluctuations of the business cycle variety. The aggregate utility function of the stand-in household had a high Frisch labor supply elasticity, much higher than the one labor economists estimated using a representative household construct.

If there are common homothetic convex preferences across households, the aggregated household's labor supply elasticity is the same as that of the individuals being aggregated. Empirically, however, these elasticities are not the same. Kydland and Prescott (1982) found that the aggregate labor supply elasticity must be in excess of 3 for the neoclassical growth model to predict business cycle fluctuations, whereas MaCurdy (1981), using panel data, estimated the labor supply elasticity of prime-age males working continuously to be only 0.15. The aggregate and disaggregate estimates must be consistent, and a reason for this difference is needed.

2.5 Why the Discrepancy between Micro and Aggregate Elasticity Estimates?

Rogerson (1984) came up with the reason for the discrepancy between micro and aggregate estimates. He observed that the principal margin of adjustment in aggregate labor supply was in the number of people working in a given week and not in the hours worked per worker. Consequently, the micro estimate of the labor supply using a theoretical structure predicting just the opposite has to be dismissed as an estimate of the aggregate labor supply elasticity. The labor economist conclusion that tax rates had little consequence for aggregate labor supply was wrong. This is an important example of the failure of micro theory in drawing *aggregate* scientific inference. Aggregation matters. This was recognized by Marshall in his classic textbook first published in 1890 and by Wicksell around the same

time. The aggregate production function, given that there is entry and exit of production units, is very different from the production functions of individual units.

Rogerson (1984) developed a formal theory of the aggregate utility function when there was labor indivisibility. This theory was developed in a static context. Hansen (1985) introduced it into the basic neoclassical growth model and found that the resulting model displayed business cycle fluctuations. This research resolved the puzzling discrepancy between micro and aggregate observations.

2.6 Why Is There Labor Indivisibility?

The puzzle of what could give rise to labor indivisibility was resolved by Hornstein and Prescott (1993), who found that if individuals' outputs of labor services is a function of the capital that each worker uses, the margin of adjustment is the number of people working and not the number of hours worked. The fraction working is the margin used up to the point at which all are working. This model endogenized labor indivisibility in a simple version of the optimal growth model. An important point is that it breaks the clean separation between preferences and technology in determining the aggregate elasticity of labor supply.

An alternative theory of labor indivisibility was subsequently developed by Prescott, Rogerson, and Wallenius (2009). The key feature of this theory is that the mapping of time allocated to the market to units of labor services supplied is not linear. The increasing mapping is initially convex. Reasons for this nonlinearity include the time needed to update information on which decisions are made and the time needed to get organized. Then the mapping becomes concave; one reason is that workers become tired and perform tasks less well or at a lower rate.

One implication of this theory is that workweeks of different lengths are different commodities. This was recognized by labor economist Sherwin Rosen (1978). Hansen and Sargent (1988) have two workweek lengths in their business cycle paper: a standard workweek and an overtime workweek. The micro evidence in support of workweeks of different lengths being different commodities is strong. For example, two half-time workers on average are paid significantly less than one full-time worker with similar human capital. Additional evidence is that the normal workweek length differs across occupations. With this theory, the reason for the differences in workweek lengths across occupations is that the mapping from time allocated to the market to units of labor services produced is different across occupations. When important nonconvexities are present, the micro and aggregate elasticities are different even if all the micro units are identical.

This is true for both the household and the business sectors. At the production unit level, investment is very lumpy, yet at the aggregate level, aggregate investment is smooth. Julia Thomas (2002) established that valuation equilibrium theory predicts that the fraction of units making discrete adjustments to production capacity will be the margin of adjustment used, as it is, and aggregate investment will be smooth.

Time series methods used to model aggregate time series use linear models. This is because there are no obvious nonlinearities in the time series. The one case in which nonlinearity was found to be significant was in the Hansen and Prescott (2005) model with a capacity utilization constraint. If capacity constraints are occasionally binding, aggregation theory leads to an aggregate production function that has a kink which results in the labor income share falling when the capacity constraint is binding. It also implies that business cycle peaks will be flatter and smaller than troughs for the detrended data as they are. This is an improvement in theory but is of second-order importance.

2.7 A Digression on Methodology of Aggregate Analysis

Theory is a set of instructions for constructing a model economy to address a given question. The criterion for a good theory is that it is useful. Models are instruments used to draw scientific inference. What constitutes a good model depends on what question is being addressed. Reality is incredibly complex, and any model is necessarily an abstraction and therefore false.

The model economy selected in a particular application is not the one that best fits a particular set of economic statistics. It must fit along selected dimensions of reality given the question. To illustrate this idea, consider the question of how much of the higher average return on publicly traded stocks is a premium for bearing aggregate risk. The highly liquid short-term debt is called the safe asset. However, it is not a perfectly safe asset, as is the model economy's safe asset. A perfectly safe asset does not exist. Government debt is not safe because governments default fully or partially in extreme events. Therefore, the nature of the consumption process in the model economy used must not have the possibility of extreme events.

The model economy that Mehra and Prescott (1985) used to address this issue had only one type of infinitely lived households and a pure endowment process. We specified a Markov chain process on the growth rate of this endowment, which rules out extreme events. Equilibrium consumption was the output of the endowment process. The relation examined was the return on the endowment process and a security that paid one unit of consumption in the next market in the sequence with certainty in the sequence of market equilibria. Empirically, the difference in average yields on equity and short-term relatively risk-free liquid debt was over 6 percent. The finding was that only a small part of the difference in average yields on the two classes of securities was accounted for by a premium for bearing nondiversifiable aggregate risk.

Will a class of model economies with a richer class of processes on consumption growth rates resolve this puzzle? The answer is no because the abstraction used permits *any* stationary process on consumption growth rates. Our abstraction did rule out extreme events because truly risk-free assets do not exist.

This finding raised the question of what factors were giving rise to this big difference. McGrattan and Prescott (2005) subsequently learned that introducing taxes on distributions by corporations to owners reduced the premium by a third. Economic theory says it is after-tax distributions that should be considered in determining the return on different assets.

Another significant factor is the cost of managing assets. Pension funds have sizable costs that reduce the return on equity realized by households who are the indirect owners of the equity held by these funds. On the other hand, the cost of managing a portfolio of short-term liquid assets is small. The magnitude of the asset management and intermediation costs can be estimated using national income and product accounts. The aggregate value of the corporate equity held either directly or indirectly by the household sector can be estimated using aggregate balance sheet statistics. The annual costs are about 2 percent of the total value of the assets. This exercise was carried out in Mehra, Piguillem, and Prescott (2011).

Most of the remainder of the difference in average yields is almost surely due to a liquidity premium for carry-out transactions. This leads to the conclusion that the equity premium puzzle is no longer a puzzle. Better measurement may identify a deviation from theory, but for the time being, theory is ahead of measurement with respect to the equity premium.

The model economy used to measure and estimate the premium for bearing nondiversifiable aggregate risk has no investment. In fact, investment is a sizable share of output. The model is not realistic along this dimension. However, this very simple model is sufficiently rich to address the question asked. The salient features of reality are incorporated into the model being used to address the given issue. The general principle is, if the question can be addressed with a simpler model, use the simpler one.

2.8 The Need for Discipline

A useful theory must have an associated discipline. Scientists, who employ the discipline and use the theory to answer a given question, reach the same conclusion as to what the theory says or does not say. Given the current state of the theory, the conclusion may state that the theory has to be extended before the question can be addressed. Or it may say that the answer depends on the magnitude of certain parameters, which have not yet been measured sufficiently accurately. The theory used in aggregate analysis is neoclassical growth theory. A crucial feature of this discipline is that when researchers extend the theory in order to resolve a deviation from theory or to expand its domain of applicability, the extended theory must be consistent with previously successful applications of the theory.

In the subsequent sections of this chapter, the development and use of neoclassical growth theory will be reviewed. This theory is applicable to virtually all substantive areas of economics including not only traditional business cycle fluctuations but also differences in per capita output levels across countries and across times. It is the theory in aggregate public finance, financial asset pricing, labor economics, monetary economics, environmental economics, and international finance.

The model economy used in an application is restricted by more disaggregated statistics. For example, the assumed time-to-build for new structures must be consistent with how long it typically takes to build a new structure. Econometricians have constructed statistical tests that rejected the Hansen (1985) model of business cycles. That model abstracted from time-to-build, because Hansen found this feature of reality to be of secondary importance in understanding business cycle fluctuations. Using data generated by the Kydland and Prescott (1982) model, which has a time-to-build technology, these statistical tests would lead to a rejection of the RBC model generating the data. It would be easy to come up with another test that would result in the rejection of the model with time-to-build. The implication is that statistical hypothesis testing is of little use in selecting a model to address some given question.

Section 3: The Nature of the Discipline

3.1 The Back and Forth between Theory and Measurement

The study of business cycle fluctuations led to the construction of dynamic stochastic general equilibrium models of these fluctuations. These early models had a quadratic household utility flow function and linear technology constraint. This research program did not produce models with national accounts that could be compared to the actual ones. Their use did not satisfy the Klein discipline. Examples of these early models include Sargent (1976) and Kydland and Prescott (1977). Another limitation was that using other observations in economics to restrict the choice of the model economy was difficult and, in some cases, impossible.

What turned out to be the big breakthrough was the use of growth theory to study business cycle fluctuations. A question is, why did it take so long before it was used for this purpose? The answer is that, based on micro theory reasoning, dynamic economic theory was viewed as being useless in understanding business cycle fluctuations. This view arose because, cyclically, leisure and consumption

moved in opposite directions. Being that these goods are both normal goods and there is little cyclical movement in their relative price, micro reasoning leads to the conclusion that leisure should move procyclically when in fact it moves strongly countercyclically. Another fact is that labor productivity is a procyclical variable; this runs counter to the prediction of micro theory that it should be countercyclical, given the aggregate labor input to production. Micro reasoning leads to the incorrect conclusion that these aggregate observations violated the law of diminishing returns.

In order to use growth theory to study business cycle fluctuations, the investment-consumption decision and the labor-leisure decision must be endogenized. Kydland and Prescott (1982) introduced an aggregate household to accomplish this. We restricted attention to the household utility function for which the model economies had a balanced growth path, and this balanced growth path displayed the growth facts. With this extension, growth theory and business cycle theory were integrated. It turned out that the predictions of dynamic aggregate theory were consistent with the business cycle facts that ran counter to the conclusion of those using microeconomic reasoning.

That time-to-build model economy had only technology shocks, so the analysis was restricted to determining the consequences of different types of technological shock processes for the cyclical behavior of the neoclassical growth model. Kydland and Prescott (1982) found if there are persistent technology shocks and the aggregate elasticity of labor supply is high, neoclassical growth theory can predict fluctuations of the business cycle variety. By construction, the model economy displayed the growth facts. However, the aggregate Frisch elasticity of labor supply is not tied down by the growth facts. Two questions needed to be answered before one could say that the neoclassical growth model displays business cycle fluctuations of the nature observed. The first question was whether the Frisch elasticity of the aggregate household labor supply was at least 3. The second question was whether technology shocks were highly persistent and of the right magnitude.

One criticism of Kydland's and my analysis was that empirically, cyclical labor productivity and total hours were roughly orthogonal during the period studied, whereas for the model economy, they were highly correlated. If productivity shocks were the only factor contributing to fluctuations, this would be a valid criticism, and business cycle fluctuations would be inconsistent with neoclassical growth theory. But productivity shocks were not the only factor giving rise to business cycle fluctuations during this period. To determine how much of the business cycle fluctuations were accounted for by productivity shocks, an estimate of the variance of these shocks was needed. This was provided by Prescott (1986). Given the estimate, labor productivity and aggregate hours worked should be roughly orthogonal, as

they were during the period studied. The finding is that the US economy would have been 70 percent as volatile as it was during the period considered if productivity shocks were the only shocks.

The nature of the shock is important in the theory. If one thinks that all productivity change is due to the growth of knowledge useful in production, productivity shocks generally should be negative; in fact, however, productivity shocks are sometimes negative. One implication is that variations in the growth of the stock of useful knowledge cannot be the only reason for changes in productivity. Another factor giving rise to changes in productivity are changes in legal and regulatory constraints. Such changes can both increase and decrease productivity. The huge differences in productivity that are observed across countries provide strong evidence that the legal and regulatory systems are of great importance in determining the level of productivity.

3.2 Monopolistic Competition: Small Consequences for Business Cycle Accounting

Neoclassical growth theory assumes price taking in market transactions. Does abstracting from the fact that some businesses and groups of factor suppliers have market power and are not price takers alter the conclusions of the simple abstraction? Hornstein (1993) introduced monopolistic competition and found that for measuring the contribution of productivity shocks to business cycle fluctuations, it mattered little. He calibrated a monopolistic competitive model to the same set of statistics as those using the neoclassical growth model did. With monopolistic competition, the response to the shocks is greater, but this is offset by a smaller estimate of the variance of the underlying productivity shock. For this purpose, abstracting from market power mattered little for the estimate of the contribution of productivity shocks to business cycle fluctuations. For some other issues, this is probably not the case. This illustrates the way in which the theory progresses. A finding is successfully challenged by showing that introducing some feature of reality in a disciplined way changes the answer to the question. The results of unsuccessful challenges are of interest, for they add to the confidence in the original study.

3.3 Nonneutral Technological Change: Little Consequence in Basic Model

The relative price of the composite investment good and the composite consumption good has not been constant, as it is in the basic neoclassical growth model. Secularly, what is more or less constant is the value of investment goods produced relative to the value of all goods produced in nominal terms. In a

world in which the relative price of the investment good falls, such as one with the following aggregate production relation:

$$c_t + (1+\gamma)^{-t} x_t \leq A\, k_t^{\theta}\, h_t^{1-\theta},$$

where $\gamma > 0$, will give rise to balanced growth with the relative price of the investment good to the consumption good falling at rate γ. Greenwood, Hercowitz, and Huffman (1988) show this. Another interesting finding in their paper concerns the nature of depreciation for the theory of business cycle fluctuations.

3.4 Nature of Depreciation: Matters

The standard abstraction for depreciation is the perpetual inventory assumption with a constant depreciation rate:

$$k_{t+1} = (1-\delta)k_t + x_t.$$

Greenwood et al. (1988) assume that the rate of depreciation increases with the intensity of the use of capital; that is, they assume a Taubman and Wilkinson (1970) depreciation technology. Let u_t denote the capital utilization rate. Capital services provided is $u_t k_t$. The depreciation rate is an increasing function of the utilization rate, $\delta_t = \delta(u_t)$. With this assumption, the response to productivity shocks is bigger and the aggregate elasticity of labor supply smaller for the model calibrated to the growth facts.

I am sure that this alternative theory of depreciation was considered by the national income and product accountants and found not to be important. It is true that during periods of high economic activity, some capital is utilized more intensely. However, for many capital goods, depreciation does not depend on the intensity of use. One reason is that during boom periods, machines are well maintained in order to keep them operating efficiently. Better maintenance lowers the depreciation rate. Higher occupancy rates of office buildings do not increase their depreciation rate. The national accounts stuck with the perpetual inventory method and useful life in calculating aggregate depreciation because it was consistent with the prices of used capital equipment. This is another example of micro evidence restricting the model economy being used to address an aggregate issue.

If this alternative theory of depreciation had passed the micro test, it would have introduced a number of discrepancies within the theory. Business cycle observations would imply a smaller aggregate labor

supply elasticity, and this in turn would imply that the theory predictions for cross-country differences in aggregate labor supply arising from differences in the marginal tax rate on labor income would be much smaller than what they are. About the only way to resolve these discrepancies would be to assume country-specific differences in preferences that give rise to both higher marginal tax rates and lower labor supply. With this resolution, however, there would be big discrepancies between the predictions of theory for aggregate labor supply during growth miracles.

The important point is that preference and technology parameters, with the discipline reviewed here, must be consistent across applications.

3.5 Monetary Policy: Little Consequence for Business Cycle Fluctuations

The general view prior to the development of quantitative aggregate economic theory was that monetary policy had important real consequences for the behavior of real variables, in particular real output and employment. Once explicit transactions abstractions were developed that gave rise to a demand for money, it was possible to introduce them into the neoclassical growth theory and to assess their quantitative consequences for real variables. Cooley and Hansen (1995) did this and found that the real consequences were small for monetary policies that did not give rise to very high rates of inflation. This supported the empirical findings of Sargent and Sims (1977) that real movements were not the result of monetary factors in the postwar US economy.

Sticky wage and nominal staggered wage contracting arrangements were subsequently introduced into the neoclassical growth model and their quantitative consequences for real findings determined by Chari, Kehoe, and McGrattan (2000). The finding was that these mechanisms did not give rise to business cycle fluctuations of the nature observed.

Another bit of strong evidence for the unimportance of monetary policy is the fact that RBC models that abstract from monetary factors do not have large deviations from observations during periods with high variations in inflation rates, such as during the period 1978–1982 in the United States.

3.6 Two Important Methodological Advances

In critiquing the use of neoclassical growth theory to study business cycle fluctuations, Summers (1986) asked a good question: What are these shocks? An important methodological advancement to the theory was needed before his question could be answered. The advancement was path analysis.

Path analysis

Hansen and Prescott (1993) used path analysis when they addressed the question of whether technology shocks caused the 1990–1991 recession. In that paper, the dynamic system for the model was used to generate time paths of the variables given the realized values of the stocks. The finding was that yes, productivity shocks did cause that recession.

That paper offered another interesting finding. A prediction of the technology-shock-only model is that the economy should have recovered in 1993–1994, since productivity had returned to trend. Other factors had to be depressing the economy during this period. Subsequently, the factors were identified. They were increases in tax rates.

Distribution of firms with inventories a state variable

A widely held view was that inventory behavior was important for understanding business cycle fluctuations given the large cyclical variability of inventory investment. The micro theory of inventory investment was developed, but introducing this feature into quantitative neoclassical growth theory was impossible given the lack of needed tools.

Fisher and Hornstein (2000) developed a way to introduce inventory investment when firms faced fixed resource costs when making an inventory investment. This made the stock of inventory a firm state variable and the distribution of firms as indexed by their inventory stock an aggregate state variable. This methodological advance was also used by Hornstein (1993) to assess the quantitative importance of monopolistic competition.

3.7 The Big Aggregate Economic Puzzle of the 1990s

A boom in output and employment in the United States began about 1994 and continued until the very end of the decade. This boom was puzzling from the perspective of what was then aggregate economic theory. In this boom, corporate profit share of gross national income was low. In other booms, this share was higher than normal. Another puzzling observation was that GDP per hour, the commonly used measure of productivity, was low in this boom. Normally, productivity accounts for about a third of the cyclical variation in GDP and market hours the other two-thirds. In this boom, the accounting was

125 percent due to market hours worked and negative 25 percent due to productivity. No changes in labor market policies or tax rates could account for these phenomena. This puzzle remained open for at least six years. One explanation consistent with general equilibrium theory was that Americans—as well as Europeans—experienced a contagious case of workaholism; that is, the rate at which people's willingness to substituted labor for leisure in the aggregate changed. Such explanations violate the discipline of dynamic aggregate theory reviewed in this essay.

To answer this question, two developments in quantitative aggregate theory were crucial. One was the use of an equilibrium condition for a class of economies that depend on current-period variables to account for the large differences in hours worked per working-age person across countries and across time. This equilibrium condition used was that the marginal rate of consumption and leisure is equal to the after-tax wage. A Cobb-Douglas production function was assumed, so the wage was just aggregate labor income divided by aggregate hours.[3] The elasticity of substitution between consumption and leisure for the aggregate household was the same as the one needed for the neoclassical growth model to display business cycle fluctuations.

The reason that Western Europeans now work 30 percent less than other advanced industrial countries is not that they are lazy or are better at making use of nonmarket productive time. It is that these countries have higher marginal tax rates on labor income and on consumption. These higher tax rates introduce a large tax wedge between the intratemporal marginal rate of substitution and the marginal rate of transformation between consumption and market time.

The second development was to use this methodology to account for the large secular movements in the value of corporations relative to GNP in the United States and the United Kingdom in the 1960–2000 period. The equilibrium relation used for the class of models considered was the following one. The market value of corporations is equal to the market value of the capital stocks owned by the firm. Given the importance of intangible capital in determining the value of corporations, this stock had to be included in the analysis. Brand names, organization capital, patents, and technology know-how embodied in the organization all contribute to the value of the business enterprise.

With these two developments, the stage was set for resolving the US hours boom of the 1990s.

[3] This is the measure of wages used by Lucas and Rapping (1969) when they introduced labor supply into macroeconometric modeling.

Section 4: Major Developments and Their Applications Post-1995

Important theoretical advancements in neoclassical growth theory have continued to occur and have expanded the theory's applicability. Also important was the development of new and better data sets that are easily accessible. These data sets are more uniform across countries, which facilitates the study of factors giving rise to international differences in economic aggregates. Increases in computing power made possible the introduction of demographics into models being used to draw scientific inference using the theory. The life cycle is crucial for understanding aggregate savings behavior as it gives rise to savings for retirement.

4.1 Clubs in the Theory and France's 35-Hour Workweek Policy

A development in valuation theory was the introduction of clubs. Clubs are arrangements that internalize externalities, whether they are positive or negative, within organizations that are small relative to the economy. One extremely important type of club is the household. In classical valuation theory, household clubs are a primitive. For each household, there is an agent that chooses an optimal point in a subset of the commodity space—that is, in that household's consumption possibility set—subject to its budget constraint. Business organizations are clubs as well. A firm is defined by its production possibility set, which is a subset of the commodity space, and the households' shares of ownership. Cole and Prescott (1997) extend valuation equilibrium theory to permit clubs.

To date, this development has been little used in quantitative aggregate analyses. To the best of my knowledge, I am aware of only one aggregate quantitative application using clubs. This application is due to Fitzgerald (1998), who uses this extension of the basic theory to predict the consequences of France's 35-hour workweek constraint. His framework has two types of households and two types of labor services: skilled and unskilled. Type 1 household can only supply unskilled labor. Type 2 household can supply either type. The important constraint is that for each firm, the work schedule of those performing the skilled and the unskilled tasks must be equal. The skilled workers' tasks include supervising, monitoring, and coordinating the unskilled workers.

The goal of the French 35-hour workweek policy was to help the unskilled and not the high paid skilled workers. It turned out that the skilled are made better off under the 35-hour workweek and the unskilled worse off, counter to this objective. The legal constraint, which changed the technology set of

a firm, had an unintended consequence. The program did have the intended consequence of increasing the employment rate of the unskilled.

4.2 Cartelization Policies and the Resolution of the US Great Depression Puzzle

Cole and Ohanian (1999) initiated a program of using the theory to study great depressions. They found a big deviation from the theory for the 1930–1939 US Great Depression. This deviation was the failure of market hours per working-age person to recover to its pre-depression level. Throughout the 1930s, market hours per working-age person were 20 to 25 percent below their pre-depression level. The reasons for depressed labor supply were not financial. No financial crises occurred during the period 1934–1939. The period had no deflation, and interest rates were low. This led Cole and Ohanian to rule out monetary policy as the reason for the depressed labor supply. Neither was the behavior of productivity the reason. Productivity recovered to trend in 1934 and subsequently stayed near the trend path.

These findings led Cole and Ohanian to search for an extension of the theory that would resolve this puzzling failure of the US economy to recover in the 1930s. They observed that relative wages in the cartelized industries increased relative to those in the noncartelized industries. Employment in the cartelized industries was the most depressed and did not recover. Those in the cartelized industries were the insiders and those in the competitive industries the outsiders. The problem Cole and Ohanian had to solve was to figure out how to introduce a cartelization arrangement into quantitative aggregate theory.

Eventually, Cole and Ohanian (2004) figured out a way and found that the cartelization policy was a major factor in accounting for the failure of the US economy to recover from the Great Depression subsequent to the recovery of productivity. They estimated that the cartelization policy alone accounted for over half of the depression in employment in the US Great Depression of the 1930s. It turned out that tax and wage policies can account for much of the remainder, so the Great Depression is no longer a puzzle.

McGrattan (2012) extended the theory to permit the consequences of expected future tax rate increases on the distributions from businesses to their owners. She found that they were important in accounting for the great decline in output in 1930. Businesses made large cash distributions to their owners rather than using cash to finance new investment. Fisher and Hornstein (2002) establish that wage policies that set the wage above equilibrium value gave rise to the Great Depression in Germany

from 1927 to 1932. The elimination of these policies late in 1932 resulted in rapid recovery from Germany's Great Depression, just as theory predicts.

4.3 Taxes and Country Labor Supply: Cross-Application Verification

The question is whether the theory used to study business cycle fluctuations accounts for the large difference in labor supply, as measured by market hours per working-age person, between Americans and Western Europeans. During the period 1993–1996, Americans worked on average 40 percent more than did the French, Italian, and Germans. This was not always the case. In the period 1970–1974, market hours per working-age person were comparable in both the United States and Western Europe and comparable to what they are now in the advanced industrial countries, with the notable exception of Western Europe.

The equilibrium relation used in Prescott (2004) to predict the difference in labor supply as a function of the effective tax rate on labor income was that the marginal rate of substitution between nonmarket productive time and consumption is equal to the after-tax real wage. A Cobb-Douglas aggregate production was assumed.

This equilibrium condition for country i can be written as

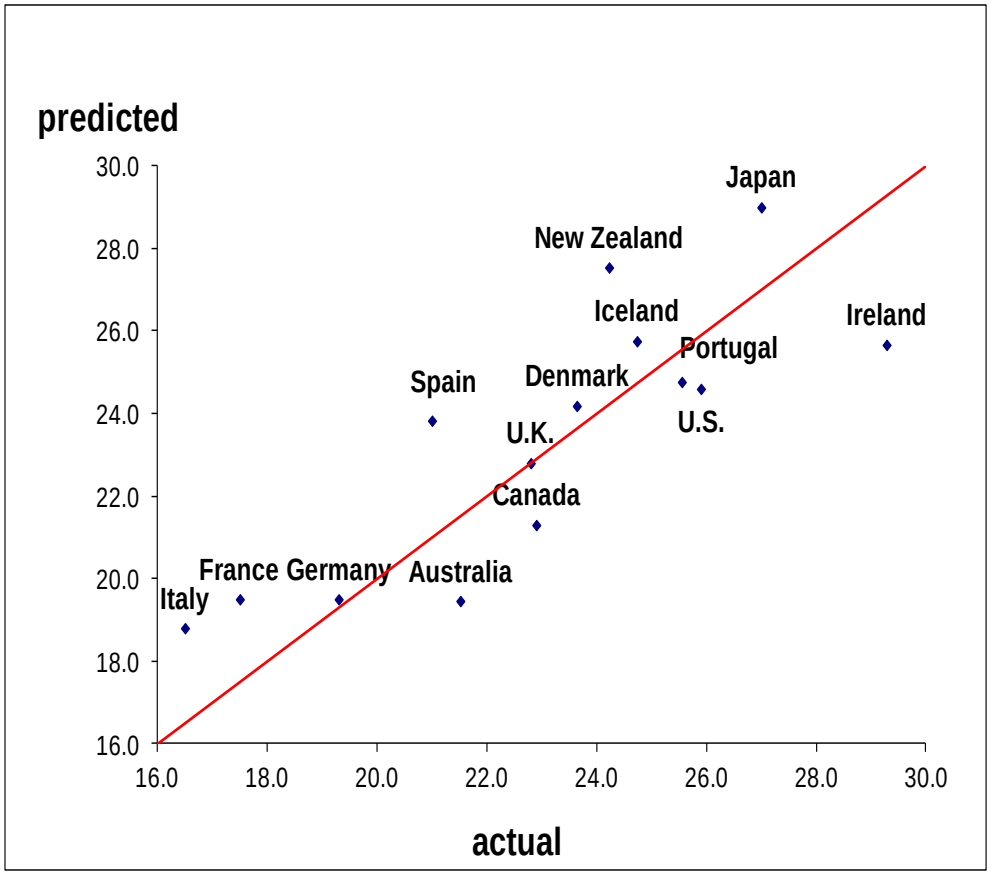
$$h_{it} = \frac{1-\theta}{1-\theta+\frac{c_{it}}{y_{it}}\frac{\alpha}{1-\tau_{it}}}$$

Here, θ is the capital share parameter, α the value of leisure parameter, h_{it} market hours per working-age person, τ_{it} the effective average marginal tax rate on labor income, and $c_{it}ly_{it}$ the fraction of aggregate output consumed.

The analysis has only one free parameter, namely, the preference parameter α. This parameter is not tied down by the balanced growth facts. The capital income share parameter was nearly constant across countries and periods and was set equal to 1/3. The preference parameter α was picked so that the relation held for the United States.

The US boom in the 1990s was unlike previously studied booms and was at variance with the basic neoclassical growth model as discussed previously. Figure 1 plots predicted and actual hours worked per working-age person for the period 1990–2002 using the model without intangible capital. It was a puzzle in the theory that remained open for eight years. No alternative theory predicted this boom.

Figure 1: Predicted and Actual Hours Worked per Working-Age Person, 1990–2002



4.4 Use of the Overlapping Generations Abstract

For many issues, it does not matter whether the dynastic family or the overlapping generation structure is used. Before the great increase in computing capabilities, using the overlapping generation structure was not feasible. Braun, Ikeda, and Joines (2009) exploited this increase in computing capabilities and found that both the dynasty and the overlapping generation constructs are consistent with the fall in Japanese savings rates in the 1990s. However, the two constructs for aggregate households imply very different behavior for the Japanese savings rate post-2010. Because of Japan's large baby boom in the 1960s, the fraction of people who were dissaving to finance retirement would increase subsequent to 2010, and the aggregate savings rate would fall. Quantitatively, the savings rate did just what the theory with an overlapping generation structure predicted it would.

Section 5: Intangible Capital Expands the Applicability of the Theory

That intangible capital investment financed and owned by firms is big has never been in dispute. A question is why intangible capital was not incorporated into quantitative aggregate theory. The answer is that there was no disciplined way to incorporate this largely unreported component of output into the theory. The development of a consistent set of balance sheets for the household and business sectors was key to resolving this problem. Balance sheets, among other things, report the value of ownership of corporate equity.

5.1 The Value of Corporate Businesses

The price of capital good K_j is $q_j(\pi)$ where π specifies tax policy. Tax policy includes not only tax rates on corporate accounting profits but also the tax rate on distributions to owners, the nature of the capital consumption allowance, and the inflation rate. An important input to production is the services of human capital owned by the employees of the corporation. It is rivalrous and does not show up in the value of corporations. Consequently, it need not be included in the model used to determine the value of corporate businesses.

The aggregate corporate market value V , where subscript T denotes tangible capital and subscript I denotes firm-owned intangible capital, is

$$V = q_T(\pi) K_T + q_I(\pi) K_I .$$

If there were no capital income taxes, the prices of capital in units of the consumption good would be 1. But there are capital income taxes.

The price of one unit of tangible capital in terms of the consumption good, given that nearly all investment is financed through retained earnings, is

$$q_T = (1 - \tau_{dist}) ,$$

where τ_{dist} is the tax rate on distributions from corporations to owners. The average marginal tax rate on distributions is used. In the 1960s, virtually all distributions were in the form of dividends. The tax rate used was the average of the individual marginal tax rates weighted by the total dividends received by the group subject to that marginal tax rate. In the 1960s, this average tax rate was about 45 percent. Beginning in the 1980s, buybacks began to be used and permitted distributions to be deferred to when the capital gains were realized. This lowered the average tax on distributions.

Intangible capital was expensed, and as a consequence its price to the owners of the businesses making the investment is smaller than the cost of producing it. The price of intangible capital is

$$q_I = (1 - \tau_{dist})(1 - \tau_{corp\ profits}) .$$

In both the United States and the United Kingdom, there were large movements in V relative to annual gross national income (GNI) over the period studied by McGrattan and Prescott (2005) using this theory. The V / GNI number varied by a factor of 2.5 in the United States and by a factor of 3.0 in the United Kingdom during the period 1860–2000. This variation was not due to variation in the ratio of after-tax corporate income to GNI. This ratio varied little over the period. The theory found that the reason for the large secular changes was due to changes in taxes and regulations. Intangible capital was an important part of the value of corporations.

The big change in the tax system that increased the value of corporations was the deferred compensation individual savings account. These accounts permitted households to save for retirement free of capital income taxes. Insofar as the withdrawals are used to finance retirement consumption,

there is no intertemporal wedge between the marginal rate of substitution between current and future consumption and the marginal rate of transformation between current and future consumption.

The added capital alone had little consequence for business cycle fluctuation accounting, so no new puzzles were created with this extension. An old puzzle that has not been resolved is the LeRoy and Porter (1981) and Shiller (1981) excess asset price volatility puzzle. Indeed, by looking at the values of the capital stocks owned by firms rather than at the present value of dividends, McGrattan and Prescott (2005) strengthened this excess volatility puzzle. These capital stocks vary smoothly, so the theory predicts their prices should as well.

In the model with intangible capital owned by business enterprises, we used an alternative aggregate production technology to the aggregate production function. There are three inputs: the services of tangible capital, the services of rival human capital, and the services of intangible capital. There are *two* output goods: one the composite output good less intangible capital investment and the other intangible capital investment. There were two *activities*: one producing intangible capital and one producing other final goods.

It is not a two-sector model because the services of intangible capital are not allocated between activities, as are the services of the other two inputs, but are used in both simultaneously by both activities. Otherwise, the production technology is standard. Letting Y_1 be output less intangible investment output, Y_2 intangible investment output, K_T tangible capital stock, K_I intangible capital stock, and L rival human capital services (labor), total output of the two activities is

$$
\begin{aligned}
Y_1 &= A_1 F_1(K_{T1}, K_I, L_1) \\
Y_2 &= A_2 F_2(K_{T2}, K_I, L_2) \\
K_T &= K_{T1} + K_{T2} \\
L &= L_1 + L_2
\end{aligned}
$$

One unit of capital produces one unit of its services. All variables implicitly have a time subscript including the productivity parameters A_1 and A_2. The functions F_1 and F_2 have all the standard properties of the aggregate production function.

The important feature of the technology is that K_I has no activity subscript. A brand name can be used to produce a product sold in the market as well as in the development of a related product. The same is

true of patents. The other two inputs are allocated between the activities. If productivity change is neutral in the sense that A_{1t} / A_{2t} stays constant, the implications for business cycles are the same. Thus, this technology works where the basic neoclassical growth model works. This part of the discipline is satisfied.

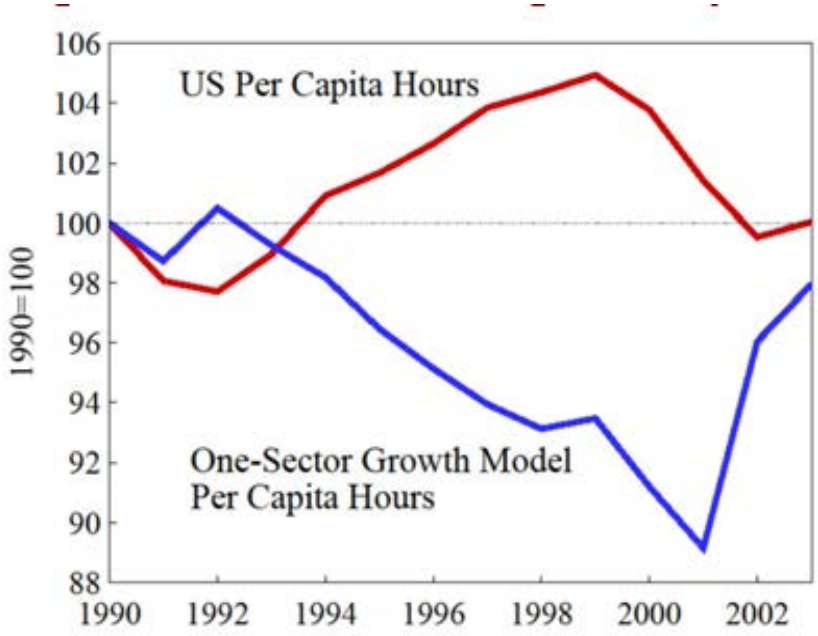
A problem is that most intangible capital investment made by firms and owned by firms is expensed and therefore not part of measured output. The question is how to incorporate this unobservable in a disciplined way. McGrattan developed a way (see McGrattan and Prescott 2010b). The size of intangible capital net investment has implications for accounting profits of the corporate sector. Knowing the initial stock, the stocks can be computed from statistics reported in the national income and product accounts (NIPA).

5.2 US Hours Boom in the 1990s: A Crisis in RBC

The basic neoclassical growth theory model accurately predicted the behavior of the US economy prior to the 1990s, taking productivity taxes and demographics as exogenous. Theory was then ahead of measurement. In the 1990s, it did not predict accurately. Market hours boomed while GDP per hour, the usual measure of productivity relative to trend, declined. The simple accounting was that the labor input accounted for 125 percent of the output and the standard measure of productivity for *minus* 25 percent. Typically, hours account for about two-thirds of the detrended change and productivity for the other third.

Taxes were not the answer, since the intratemporal tax wedge was, if anything, larger than before the boom. There were no major labor market reforms that improved the performance of the labor market. Economists were faced with the puzzle of why people were working so much. Figure 2 plots the predicted and actual paths using the basic growth model without the introduction of intangible capital into the theory.

Figure 2: Without Intangible Capital: Big Deviation from Theory

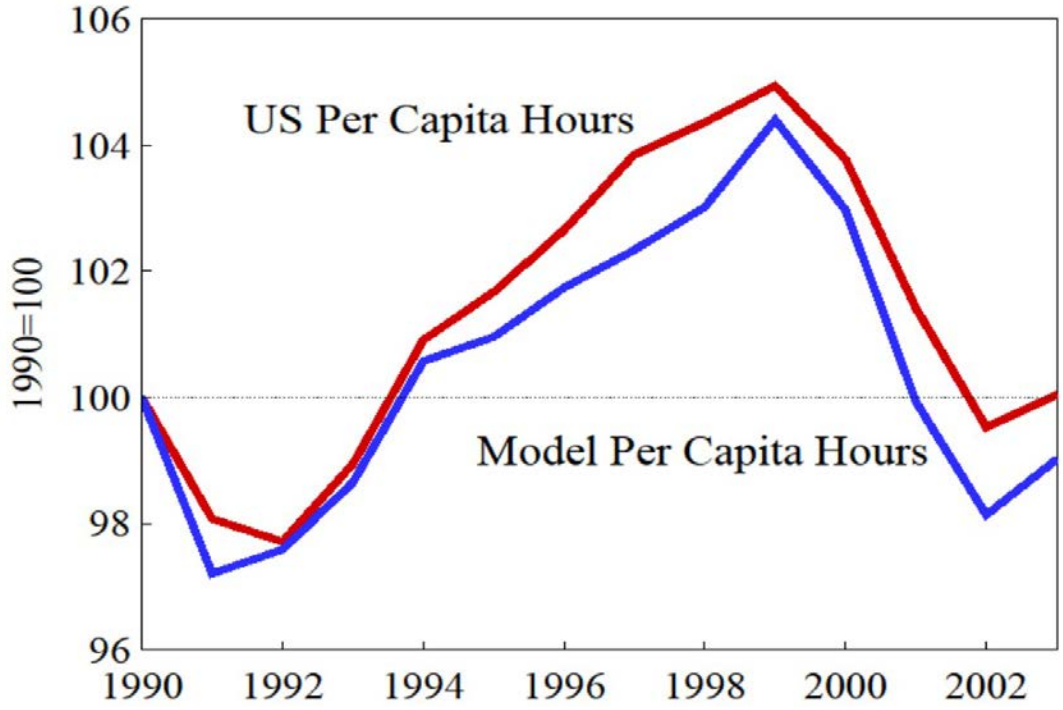


It was recognized that large investments in intangible capital were being made, and most were not reported as part of output because they were expensed. At the time, only computer software investment was reported.

Aggregate economics is not the only science with unobservable variables. A translation of a quote by Albert Einstein reads: “Not everything that counts can be counted, and not everything that can be counted counts.” The key relation is the accounting profit equation. The bigger the net unmeasured intangible investment, the smaller were these problems. This finding, along with the fact that accounting profits were a small share of GDP in this hours boom period, is consistent with intangible investment being large. Other evidence is from the National Science Foundation. The NSF provides estimates of private R&D expenditures, which are an important component of intangible capital investment. These investment expenditures in percentage terms increased much more than measured investment expenditures during the 1990s boom.

With the introduction of intangible capital and nonneutral technology change in the production of GDP and intangible capital investment, measurement was again in conformity with theory. This is shown in Figure 3.

Figure 3: With Intangible Capital: No Deviation from Theory



The extended theory accounts for capital gains reported in the Federal Reserve System's flow of funds accounts. About half of these investments are financed by the owners of corporations subject to the corporate income tax and half by worker-owners of other businesses, which matches with micro observations.

5.3 Technology Capital

Intangible capital falls into different categories. Some are specific to the local production units and market. Some are assets with services that can be used at multiple locations. Virtually every metropolitan area in the United States has the same set of major retailers. Each of these major retailers uses the same know-how and name for all their retail outlets. The branches rely on their central headquarters for supply-side management, financial services, and advertising services. Intangible capital that can be used at multiple locations is technology capital. Investment in this type of capital is financed by location rents.

There are no increasing returns to scale, even though a closed economy with more locations will be richer than a closed economy with fewer locations, other things being equal. A production unit at a given location faces decreasing returns to scale. The production unit, being a price taker, realizes location rents. With technology capital, a reason for foreign direct investment exists.

5.4 Use in Estimating Gains from Openness

Estimating gains from openness was originally introduced to study the role of openness in economic development (see McGrattan and Prescott 2009). The observation was that for 50 years prior to World War II, the EU-6 GDP labor productivity was only a little more than half that of the United States, as it was in 1957 when the Treaty of Rome was signed. In the subsequent 30 years, EU-6 productivity caught up to that in the United States. This strongly suggests that openness fosters economic development. The role of trade can account for only one-ninth of the gain if the model used in the estimation is restricted to be consistent with the trade flows. Technology capital accounts for about one-third. This evidence indicates that other factors associated with openness are even more important. Two factors that have not yet been incorporated into the theory that empirically seem important are the faster diffusion of public knowledge and increasing competition reducing barriers to adopting more efficient technologies in production.

The technology extension has already permitted the theory to be used to assess China's direct foreign investment policy. Holmes, McGrattan, and Prescott (2015) find that the Chinese policy of requiring access to technology capital of the foreign multinational making foreign direct investment in China in return for access to the huge Chinese market was in China's economic interest. In making these restrictions, China is violating the rules of the World Trade Organization. With the renminbi gaining reserve currency, interest in becoming more open to direct foreign investment will increase in China. This illustrates the usefulness of the theory in still another area, and, as stated earlier, usefulness is one criterion for a successful scientific theory.

5.5 Use in Accounting for Features of US Current Accounts

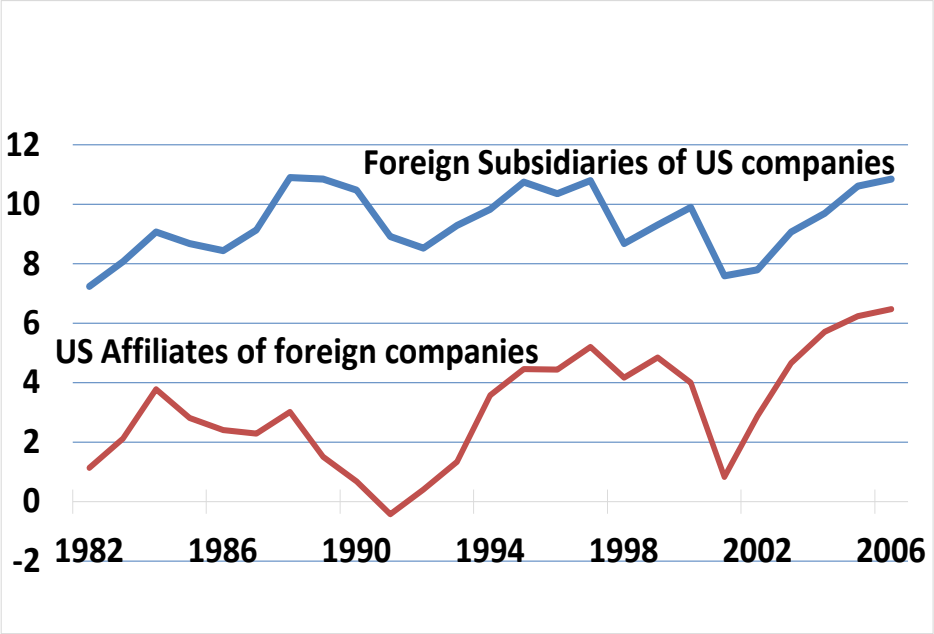
A feature of US current accounts is the high reported earnings of US companies on their foreign direct investment (FDI) and the low reported earnings of foreign companies' FDI in the United States. As reported by the Bureau of Economic Analysis (BEA), during the period 1982–2005, US companies earned an average return of 9.3 percentage points on their FDI, whereas foreign companies earned an average of 3.0 percentage points on their US FDI. Annual average returns for the period are plotted in Figure 4.

A question addressed by McGrattan and Prescott (2010b), naturally arises: why is the return differential so large and persistent?

The introduction of technology capital accounts for over 60 percent of the difference. Intangible capital investment stock is important because it increases profits but not the BEA stock of capital. It does increase the stock of capital, which lowers the economic return. US multinationals made large FDI earlier and, as a result, have relatively larger stocks of intangible capital than foreign multinationals have in their US subsidiaries. The age of the foreign subsidiaries matters because intangible investment is high and therefore BEA profits low when they are young. This micro evidence strongly supports the theory.

Using economic returns, the differential between average return on US FDI and the average return on foreigners' FDI is reduced from 6.3 percentage points to about 2.5 percentage points. A question that naturally arises is, what accounts for the remaining 40 percent of the difference? Corporate tax rates differ across countries, and through transfer pricing, profits are shifted to countries where this tax rate is lower. Indeed, an important field of corporate finance is concerned with setting prices for goods and services transferred between multinationals and their foreign subsidiaries.

Figure 4: BEA Average FDI Annual Returns



Section 6: Concluding Comments

So much has been learned through the successful use of neoclassical growth theory and its extensions. This theory has directed the development of aggregate economics. The availability of better data sets is fostering further development. As these better data sets become available, great progress is being made in incorporating features of the household sector,[4] which like the business sector, is of great economic importance. In the earlier stages of the development and use of neoclassical growth theory, the household was a primitive. Now, however, its structure is becoming an endogenous element. The household sector has changed significantly over time and is not policy invariant.

In reporting household sector statistics, a household is the set of people residing at a dwelling— that is a postal address. The size of households has changed significantly in the United States. Further, many households consist of married couples. Over time, the nature of matching has changed, as found by Greenwood, Guner, Kocharkov, and Santos (2016). They find an important change is the increase in positive assortative matching. With more two professional households, these changes have had major consequences for the distribution of household incomes.

Another important economic sector is the government sector. The question of how a group of people can set up sustainable collective government arrangements that result in outcomes preferred by the members of this group is an important one. Answering this question will require developments in pure theory.

Through the interaction of theory and measurement, the rapid development of quantitative aggregate economic theory is certain to continue. It will be interesting to see what these developments are.

[4] McGrattan, Rogerson, and Wright (1997) introduce home production by the household into the theory. The implications for business cycles did not change.

REFERENCES

Adelman, I., Adelman, F.: The dynamic properties of the Klein-Goldberger model. Econometrica **27**(4), 596-625 (1959)

Arkolakis, C., Costinot, C., Rodríquez-Clare, A.: New trade models, same old gains? Amer. Econ. Rev. **102**(1)**,** 94-103 (2012)

Braun, R. A., Ikeda, D, Joines, D. H.: The saving rate in Japan: Why it has fallen and why it will remain low. Int. Econ. Rev. **50**(1), 291-321 (2009)

Chari, V. V., Kehoe, P., McGrattan, E. R.: Sticky price models of the business cycle: can the contract multiplier solve the persistence problem? Econometrica **68**(5), 1151-1179 (2000)

Cole, H. L., Ohanian, L. E.: The Great Depression in the United States from a neoclassical perspective. Fed. Reserve Bank Minneapolis Quart. Rev. **23**(1), 2-24 (1999)

Cole, H. L., Ohanian, L. E.: New Deal policies and the persistence of the Great Depression: a general equilibrium analysis. J. Polit. Econ. **112**(4), 779-816 (2004)

Cole, H. L., Prescott, E. C.: Valuation equilibrium with clubs. J. Econ. Theory **74**(1), 19-39 (1997)

Cooley, T. F., Hansen, G. D.: Money and the business cycle. In Frontiers of Business Cycle Research, Cooley, T. F. (ed.). Princeton, NJ: Princeton University Press (1995)

Fisher, J. D. M., Hornstein, A.: (*S,s*) inventory policies in general equilibrium. Rev. Econ. Stud. **67**(1), 117-145 (2000)

Fisher, J. D. M., Hornstein, A.: The role of real wages, productivity, and fiscal policy in Germany's Great Depression 1928-1937. Rev. Econ. Dynam. **5**(1), 100-127 (2002)

Fitzgerald, T. J.: Work schedules, wages, and employment in a general equilibrium model with team production. Rev. Econ. Dynam. **1**(4), 809-834 (1998)

Frisch, R.: Propagation problems and impulse problems in dynamic economics. In Economic Essays in Honour of Gustav Cassel. London: Allen & Unwin (1933)

Frisch, R.: From utopian theory to practical applications: the case of econometrics. Lecture to the Memory of Alfred Nobel, June 17, 1970

Greenwood, J., Guner, N., Kocharkov, G., Santos C.: Technology and the changing family: A unified model of marriage, divorce, educational attainment and married female labor-force participation. Amer. Econ. J.: Macro. **8**(1), 1-41 (2016)

Greenwood, J., Hercowitz, Z., Huffman, G. W.: Investment, capacity utilization, and the real business cycle. Amer. Econ. Rev. **78** (3), 402-417 (1988)

Hansen, G. D.: Indivisible labor and the business cycle. J. Monet. Econ. **16**(3), 309-327 (1985)

Hansen, G. D., Prescott, E. C.: Did technology shocks cause the 1990-1991 recession? Amer. Econ. Rev. **83**(2), 280-286 (1993)

Hansen, G. D., Prescott, E. C.: Capacity constraints, asymmetries, and the business cycle. Rev. Econ. Dynam. **8**(4), 850-865 (2005)

Hansen, G. D., Sargent, T. J.: Straight time and overtime in general equilibrium. J. Monet. Econ. **21**(213), 281-304 (1988)

Hodrick, R. J., Prescott, E. C.: Post-war U.S. business cycles: an empirical investigation. Discussion Paper No. 451, Northwestern University, 1-28 (1980)

Holmes, T. J., McGrattan, E. R, Prescott, E. C.: Quid pro quo: technology capital transfers for market access in China. Rev. Econ. Stud. **82**(3), 1154-1193 (2015)

Hornstein, A.: Monopolistic competition, increasing returns to scale, and the importance of productivity shocks. J. Monet. Econ. **31**(3), 299-316 (1993)

Hornstein, A., Prescott, E. C.: The firm and the plant in general equilibrium theory. In General Equilibrium, Growth, and Trade II: The Legacy of Lionel McKenzie, Becker, R., Boldrin, R., Jones, R., and Thomson, W. (eds.). San Diego: Academic Press, 393-410 (1993)

Kaldor, N.: A model of economic growth. Econ. J. **67**(268), 591-624 (1957)

Kondratieff, N. D., Stolper, W. F.: The long waves in economic life. Rev. Econ. Statist. **17**(6), 105-115 (1935)

Kuznets, S.: Secular movements in production and prices: their nature and their bearing upon cyclical fluctuations. Amer. Econ. Rev. **20**(4), 787-789 (1930)

Kydland, F. E., Prescott, E. C.: Rules rather than discretion: The inconsistency of optimal plans. J. Polit. Econ. **85**(3), 473-491 (1977)

Kydland, F. E., Prescott, E. C.: Time to build and aggregate fluctuations. Econometrica **50**(6), 1345-1370 (1982)

LeRoy, S. F., Porter, R. D.: The present-value relation: Tests based on implied variance bounds. Econometrica **49**(3), 555-574 (1981)

Lucas, R.E., Jr.: Expectations and the neutrality of money. J. Econ. Theory **4**(2), 103-123 (1972)

Lucas, R. E., Jr.: Econometric policy evaluation: a critique. Carnegie-Rochester Conf. Ser. Public Pol. **1**, 19-46 (1976a)

Lucas, R. E., Jr.: Understanding business cycles. Carnegie-Rochester Conf. Ser. Public Pol. **5**, 7-29 (1976b)

Lucas, R. E., Jr., Rapping, L. A.: Real wages, employment and inflation. J. Polit. Econ. **77**(5), 721–754 (1969)

Lucas, R. E., Jr., Sargent, T. J.: After Keynesian macroeconomics. Fed. Reserve Bank Minneapolis Quart. Rev. **3**(2), 1-16 (1979)

MaCurdy, T. E.: An empirical model of labor supply in a life cycle setting. J. Polit. Econ. **89**(6), 1059-1085 (1981)

McGrattan, E. R.: Capital taxation during the U.S. Great Depression. Quart. J. Econ. **127**(3): 1515–1550 (2012)

McGrattan, E. R., Prescott, E. C.: Taxes, regulations, and the value of U.S. and U.K. corporations. Rev. Econ. Stud. **72**(3), 767-796 (2005)

McGrattan, E. R., Prescott, E. C.: Openness, technology capital, and development. J. Econ. Theory **144**(6), 2454–2476 (2009)

McGrattan, E. R., Prescott, E. C.: Technology capital and the U.S. current account. Amer. Econ. Rev. **100**(4), 1493–1522 (2010a)

McGrattan, E. R., Prescott, E. C.: Unmeasured investment and the puzzling U.S. boom in the 1990s. Amer. Econ. J.: Macro. **2**(4), 88-123 (2010b)

McGrattan, E. R., Rogerson, R., Wright, R.: An equilibrium model of the business cycle with household production and fiscal policy. Int. Econ. Rev. **38**(2), 267-290 (1997)

Mehra, R., Piguillem, F., Prescott, E. C.: Costly financial intermediation in neoclassical growth theory. Quant. Econ. **2**(1), 1-36 (2011)

Mehra, R., Prescott, E. C.: The equity premium: a puzzle. J. Monet. Econ. **15**(2), 145-161 (1985)

Mitchell, W.: Business cycles. Berkeley: University of California Press (1913)

Mitchell, W.: Business cycles: the problem and its setting. New York: National Bureau of Economic Research (1927)

Prescott, E.C.: Theory ahead of business cycle measurement. Fed. Reserve Bank Minneapolis Quart. Rev. **10**(4) 1986, 9-22 (1986)

Prescott, E. C.: Why do Americans work so much more than Europeans? Fed. Reserve Bank Minneapolis Quart. Rev. **28**(1), 2-13 (2004)

Prescott, E. C., Rogerson, R., Wallenius, J.: Lifetime aggregate labor supply with endogenous workweek length. Rev. Econ. Dynam. **12**(1), 23-36 (2009)

Rogerson, R.: Topics in the theory of labor markets. PhD Thesis, University of Minnesota (1984)

Rosen, S.: The supply of work schedules and employment. In Work Time and Employment. Washington, DC: National Commission for Manpower Policy (1978)

Samuelson, P. A.: A synthesis of the principle of acceleration and the multiplier. J. Polit. Econ. **47**(6), 786-797 (1939)

Sargent, T. J.: A classical macroeconometric model for the United States. J. Polit. Econ. **84**(2), 207-238 (1976)

Sargent, T. J., Sims, C. A.: Business cycle modeling without pretending to have too much *a priori* economic theory. In New Methods in Business Cycle Research: Proceedings from a Conference, Sims, C. A. (ed.). Minneapolis: Federal Reserve Bank of Minneapolis, 45-110 (1977)

Shiller, R. J.: Do stock prices move too much to be justified by subsequent changes in dividends? Amer. Econ. Rev. **71**(3), 421-436 (1981)

Solow, R. M.: A contribution to the theory of economic growth. Quant. J. Econ. **70**(1), 65–94 (1956)

Summers, L. H.: Some skeptical observations on real business cycle theory. Fed. Reserve Bank Minneapolis Quart. Rev. **10**(4), 23-27 (1986)

Swan, T. W.: Economic growth and capital accumulation. Econ. Rec. **32**(2), 334–361 (1956)

Taubman, P., Wilkinson, M.: User cost, capital utilization and investment theory. Int. Econ. Rev. **11**(2), 209-215 (1970)

Thomas, J. K.: Is lumpy investment relevant for the business cycle? J. Polit. Econ. **110**(3), 508-534 (2002)

Tinbergen, J.: Business cycles in the United Kingdom, 1870-1914. Econ. J. **62**(248), 872-875 (1952)

Wicksell, K.: Ett bidrag till krisernas teori. Review of Goda och daliga tider. Ekonomisk Tidskrift **20**(2), 66-75 (1918)