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by

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1. INTRODUCTION

What I am going to describe for you is a revolution in macroeconomics, a transformation in methodology that has reshaped how we conduct our science. Prior to the transformation, macroeconomics was largely separate from the rest of economics. Indeed, some considered the study of macroeconomics fundamentally different and thought there was no hope of integrating macroeconomics with the rest of economics, that is, with neoclassical economics. Others held the view that neoclassical foundations for the empirically determined macro relations would in time be developed. Neither view proved correct.

Finn Kydland and I have been lucky to be a part of this revolution, and my address will focus heavily on our role in advancing this transformation. Now, all stories about transformation have three essential parts: the time prior to the key change, the transformative era, and the new period that has been impacted by the change. And that is the story I am going to tell: how macroeconomic policy and research changed as the result of the transformation of macroeconomics from constructing a system of equations of the national accounts to an investigation of dynamic stochastic economies.

Macroeconomics has progressed beyond the stage of searching for a theory to the stage of deriving the implications of theory. In this way, macroeconomics has become like the natural sciences. Unlike the natural sciences, though, macroeconomics involves people making decisions based upon what they think will happen, and what will happen depends upon what decisions they make. This means that the concept of equilibrium must be dynamic, and – as we shall see – this dynamism is at the core of modern macroeconomics.

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Before proceeding, I want to emphasize that the methodology that transformed macroeconomics is applicable to the study of virtually all fields of economics. In fact, the meaning of the word *macroeconomics* has changed to refer to the tools being used rather than just to the study of business cycle fluctuations.

As a result of the transformation, these are exciting times in macroeconomics. The methodology that Finn and I developed for the study of business cycle fluctuations is being used to advance learning not only in the area of business cycles but also in virtually all areas of economics. By using this methodology, researchers are able to apply theory and measurement to answer questions, define puzzles, and determine where better measurement is needed before specific questions can be answered.

Over the last five years, I have addressed the following questions using this methodology: What is the fundamental value of the stock market, and do fundamentals account for the large movements in the value of the stock market relative to gross domestic product that have occurred over time? Why did hours worked per adult fall by one-third in Western Europe, and not in Canada and the United States, in the 1970–1995 period? Why were market hours in the United States at the end of the 1990s 5 percent above what theory predicts? Why did Japan lose a decade of growth beginning in 1992, a decade when growth was at trend in the other advanced industrial countries?

Much of this recent research originates from my undergraduate teaching that began in the late 1990s. Until then, I had never taught a course in which macroeconomic questions were addressed using this methodology. The undergraduate course I taught was Quantitative Analysis of the Macroeconomy. I chose to teach this course because I felt there was a need to develop material that could be used in teaching what macroeconomics has become at the undergraduate level. I felt there was this need because Finn's and my work on the time consistency problem and developments in agency theory led me to the conclusion that having good macroeconomic policy requires having an educated citizenry that can evaluate macroeconomic policy. A second reason why I thought there was this need is that by introducing talented undergraduates to the excitement of modern macroeconomics, some would be influenced to pursue careers in economic research and would make important advances to economic science.

In the course I introduced the real business cycle model economy, which is the single sector growth model in which people decide how much of their income to consume and save and how much of their time endowment to allocate to the market. Motivated by Ragnar Frisch's Nobel address (1970), I call this model the neoclassical growth model because it incorporates the willingness of people to substitute as well as their ability to substitute.

One decision that people must make is how to allocate their time endowment, which is the most precious resource an individual has. Indeed, as my undergraduates figure out, the present value of their time endowment is approximately 5 million current U.S. dollars, which makes them all multimillionaires. Another crucial feature of any real business cycle model is that the model people decide how much to consume and how much to invest or equivalently save.

The course requires students to carry out quantitative analyses to address specific questions. They use the methodology that Finn and I developed for the study of business cycles to address policy issues. A typical exercise is to determine whether a proposal made by a public opinion leader or government official will have the intended consequence. One question they were assigned concerns financing of transfer payments. Their finding was totally counter to then-conventional wisdom. I will return to this finding later because it is an implication of Finn Kydland's and my business cycle theory.

2. THE TRANSFORMATION OF MACROECONOMIC POLICY

In this section I first describe what macroeconomic models were before the transformation and what they are after the transformation. Then I describe policy selection before and after the transformation. Before the transformation, what is evaluated is a policy *action given the current situation*. Policy discussions were in terms of questions such as whether the money supply should be increased or reduced. In his critique (1976), Robert Lucas established that questions such as these are not well posed in the language of dynamic economic theory.

After the transformation, what is evaluated is a policy *rule*. A policy rule specifies the current policy action as a function of the current economic situation. As Finn and I found, no best policy rule exists. Typically, the policy rule is best given that it will be followed in the future. Any such rule is by definition time-consistent, but except in empirically uninteresting cases, Finn and I show that time-consistent rules are not optimal; indeed, they lead to bad outcomes. All that can be hoped for is to follow a good rule, and this requires economic and political institutions that sustain this rule.

Macroeconomic Models before the Transformation

Macroeconomic models were systems of equations that determined current outcomes given the values of the current policy *actions*, values of predetermined variables, and values of any stochastic shocks. Thus, physical models and pre-transformation macro models have the same mathematical structure. The basic mathematical structure of both is

$$x_{t+1} = f(x_t, u_t, \varepsilon_t).$$

The state or position of the dynamic system at the beginning of period t is x_t , the control or policy variables are u_t , and the stochastic shocks are ε_t .

With the system-of-equations approach, each equation in the system is determined up to a set of parameters. The simple prototype system-of-equations macro model has a consumption function, an investment equation, a money demand function, and a Phillips curve. Behind all these equations were a rich empirical literature and, in the case of the consumption function, money demand function, and investment equation, some serious theoretical work. The final step was to use the tools of statistical estimation theory to select the parameters that define the function f .

I worked in this tradition. In my dissertation, I formulated the optimal policy selection problem as a Bayesian sequential decision problem. The problem is a difficult one because the policy actions taken today affect the distribution of the posterior distribution of the values of the coefficients of the equations.

The macroeconomic models organized the field. Success in macroeconomics was to have your equation incorporated into the macroeconomic models. Indeed, Lucas and I were searching for a better investment equation when in 1969 we wrote our paper “Investment under Uncertainty,” a paper that was published two years later in 1971.

A key assumption in the system-of-equations approach is that the equations are *policy invariant*. As Lucas points out in his critique, which I delivered in 1973, this assumption is inconsistent with dynamic economic theory. His insight made it clear that there was no hope for the neoclassical synthesis – that is, the development of neoclassical underpinnings of the system-of-equations macro models.

Fortunately, with advances in dynamic economic theory an alternative set of tractable macro models was developed for drawing scientific inference. The key development was recursive competitive equilibrium theory in Lucas and Prescott (1971) and Lucas (1972). Equilibrium being represented as a set of stochastic processes with stationary transition probabilities was crucial to the revolution in macroeconomics.

Macroeconomic Models after the Transformation

Models after the transformation are dynamic, fully articulated model economies in the general equilibrium sense of the word *economy*. Model people maximize utility given the price system, policy, and their consumption possibility set; firms maximize profits given their technology set, the price system, and policy; and markets clear. Preferences, on the one hand, describe what people choose from a given choice set. Technology, on the other hand, specifies what outputs can be produced given the inputs. *Preferences and technology are policy invariant*. They are the data of the theory and not the equations as in the system-of-equations approach. With the general equilibrium approach, empirical knowledge is organized around preferences and technology, in sharp contrast to the system-of-equations approach, which organizes knowledge about equations that specify the behavior of aggregations of households and firms.

The Time Inconsistency of Optimal Policy

Before the transformation, optimal policy selection was a matter of solving what the physical scientists called a control problem. This is not surprising, given that the system-of-equations approach was borrowed from the physical sciences. With such systems, the principle of optimality holds – that is, it is best to choose at each point in time policy action that is best given the current situation and the rules by which policy will be selected in the future. The optimal policy is time-consistent, and dynamic programming techniques can be used to find the optimal policy as in the physical sciences. This is true even if there is uncertainty in the model economy.

Finn and I had read the Lucas critique and knew that for dynamic equilibrium models, only policy rules could be evaluated. This led us to search for a best rule to follow, where a rule specifies policy actions as a function of the state or position of the economy. We had worked on this problem before Finn left Carnegie Mellon to join the faculty of the Norwegian School of Business and Economics in 1973. In academic year 1974–1975 I visited the Norwegian School of Business and Economics, and in the spring of 1975 Finn and I returned to this problem. This is when we wrote our paper “Rules Rather than Discretion: The Inconsistency of Optimal Plans,” one of the two papers for which Finn and I were awarded the Nobel Prize.

In previous research we had considered time-consistent stationary policy rules. These rules have the property that they are a fixed point of the mapping that specifies the best rule today as a function of the rule that will be used in the future. The fact that these rules were not optimal led us to our key insight: the best event-contingent policy plan is not time-consistent. By this I mean the continuation of a plan is not optimal at some future point in the event-time tree. For example, it is always best to tax the returns on existing capital but not tax the returns on new investments. The reason is that a tax on existing capital is a lump-sum tax and there is no associated distortion, whereas any taxes on future returns of current investments are distortionary. But capital investments today become existing capital tomorrow, and tomorrow the best policy action is to tax their returns.

This leads to the conclusion that being able to commit has value and that having discretion has costs. The only method of commitment is to follow rules. That is why we concluded that the time inconsistency of optimal plans necessitates following rules. Some societies have had considerable success in following good, but time-inconsistent, policy rules, and as a result their citizens enjoy a higher standard of living. Other societies have limited success in this regard, and as a result their citizens suffer economic hardships.

This need for rules in organizational settings has long been recognized. That is why all agree that rule by a good set of laws is desirable. Rule by law is a political institution to get around the time consistency problem. What was new in our research was that this principle holds for macroeconomic policy counter to what everyone thought at the time.

A Success in Following a Good Monetary Policy Rule

A notable example of a success in following a good, but time-inconsistent, rule is the one maintaining a low and stable inflation rate. Before describing an institution that is proving effective in getting commitment to this good rule in many countries, I will first describe one reason why the price stability policy rule is time-inconsistent.

Consider an economy in which the nominal wage rate is set above the market clearing level in some sectors, given the inflation rate specified by the rule. This outcome could be the result of industry insiders in each of a number of industries finding this action in their best interest, given the wages chosen by the insiders in other industries and the expected inflation rate. If the price stability

policy rule is followed, ex post a distortion occurs that results in low employment. This distortion can be reduced by having inflation in excess of the amount specified by the rule. With the time-consistent monetary policy rule, inflation will be at that level where the marginal value of higher inflation in reducing the distortion will just equal the marginal cost of the higher inflation. The equilibrium outcome is high inflation and no reduction in the distortion. Commitment to the best rule will not result in high inflation, just the labor market distortion.

I turn now to an institution that is proving successful in sustaining this rule: an independent central bank. Members of this organization have a vested interest in following this rule, for if it is not followed, they would incur the risk that they would suffer in the future. If inflation has been excessive and a new administration is elected, people in the organization will be replaced and the size of the central bank cut. Thus, members of this organization have a vested interest in the rule being followed.

The increased stability of the economy and the improved performance of the payment and credit system may be due in part to the diffusion of findings of Finn's and my "Rules Rather than Discretion" paper. People now recognize much better the importance of having good macroeconomic institutions such as an independent central bank.

To find the time-consistent policy we *de facto* considered a game. In the simplest case, the value function of an individual is $v(k, K)$ and that of the policy maker $v(K, K)$, where k is a given individual's capital stock and K is the capital stock of all others. Note that within the class of policies that treat individuals anonymously, all individuals order policies in the same way as does the policy maker. At the first stage of each period, the policy maker selects the policy that is best for the representative individual and the rule by which policy will be selected in the future.

3. THE TRANSFORMATION OF MACROECONOMIC RESEARCH

The title of this address is "The Transformation of Macroeconomic Policy and Research." I turn now to the research part of the title. The methods used in macroeconomic research were different prior to Finn's and my paper, "Time to Build and Aggregate Fluctuations" (1982). The new methodology was developed in the summer of 1980 when Finn and I did the research and wrote the first draft of our "Time to Build" paper. We also wrote the first draft of this paper that summer.

Before specifying the new research methodology, I have to discuss what the key business cycle facts are and why they led economists to falsely conclude that business cycle fluctuations were not in large part equilibrium responses to real shocks. Then I will specify the methodology that Finn and I developed and used to quantitatively determine the consequences of these shocks for business cycle fluctuations.

I emphasize that what is important is the methodology and that this methodology can be and has been used to quantitatively determine the consequences of both nominal and real shocks. By using these methods, the

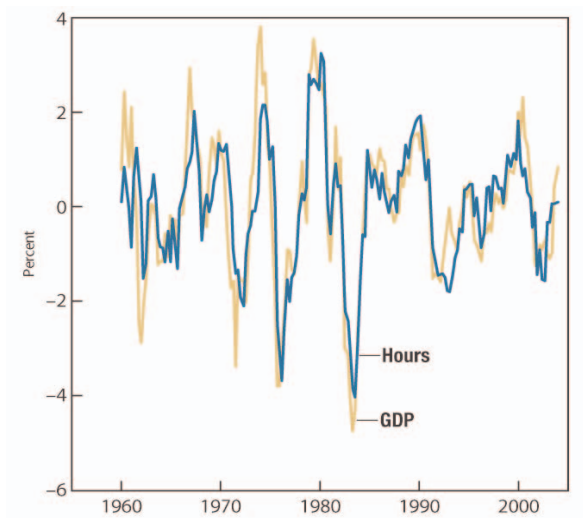


Figure 1. Deviations from Trend of U.S. GDP and Hours.

profession has learned so much. No longer do economists conjecture and speculate. Instead they make quantitative statements as to the consequences of various shocks and features of reality for business cycle fluctuations. This paper began a constructive and fruitful research program.

3.1 Business cycle facts

In the 1970s after the development of dynamic economic theory, it was clear that something other than the system-of-equations approach was needed if macroeconomics was to be integrated with the rest of economics. I want to emphasize that macroeconomics then meant business cycle fluctuations. Growth theory, even though it dealt with the same set of aggregate economic variables, was part of what was then called microeconomics, as was the study of tax policies in public finance.

Business cycles are fluctuations in output and employment about *trend*. But what is trend? Having been trained as a statistician, I naturally looked to theory to provide the definition of trend, with the plan to then use the tools of statistics to estimate or measure it. But theory provided no definition of trend, so in 1978 Bob Hodrick and I took the then-radical step of using an operational definition of trend.¹ With an operational definition, the concept is defined by the procedure used to determine the value of the concept.

¹ A shortened version of this 1978 Carnegie Mellon working paper, a copy of which I do not have, is a 1980 Northwestern University working paper. At the time, this paper was largely ignored because the profession was not using the neoclassical growth model to think about business cycle fluctuations. But once the then-young people in the profession started using the neoclassical growth model to think about business cycles, the profession found the statistics reported in this paper of interest.

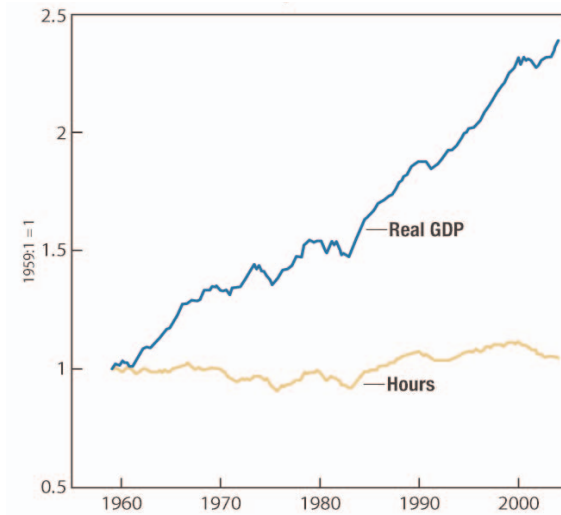


Figure 2. Indices of Per Capita Real GDP and Hours.

Our trend is just a well-defined statistic, where a statistic is a real valued function. Hodrick and Prescott's (1980) trend statistic mimics well the smooth curve that economists fit through the data. The family of trends we considered is one-dimensional. The one in the family that we used is the first one we considered. Later we learned that the actuaries use this family of smoothers, as did John von Neumann when he worked on ballistic problems for the U.S. government during World War II.² A desirable feature of this definition is that with the selection of smoothing parameters for quarterly time series, there are no degrees of freedom and the business cycle statistics are not a matter of judgment. Having everyone looking at the same set of statistics facilitated the development of business cycle theory by making studies comparable.

One set of key business cycle facts are that two-thirds of business cycle fluctuations are accounted for by variations in the labor input, one-third by variations in total factor productivity, and virtually zero by variations in the capital service input. The importance of variation in the labor input can be seen in Figure 1.

This is in sharp contrast to the secular behavior of the labor input and output, which is shown in Figure 2. Secularly, per capita output has a strong upward trend, while the per capita labor input shows no trend.

A second business cycle fact is that consumption moves procyclically; that is, the cyclical component of consumption moves up and down with the cyclical component of output. A third fact is that in percentage terms, invest-

² See Stigler's (1978) history of statistics.

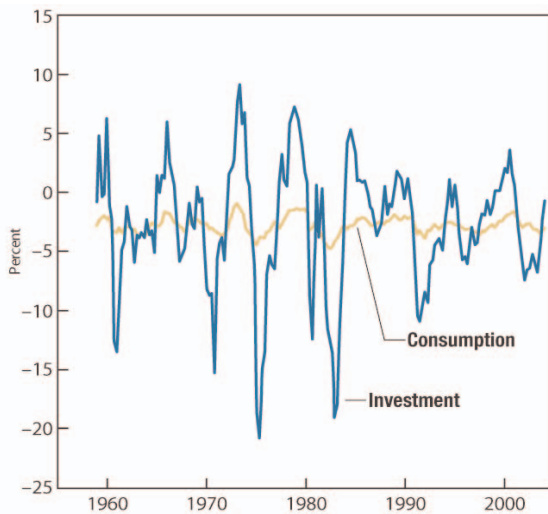


Figure 3. Deviations from Trend of U.S. Consumption and Investment.

ment varies 10 times as much as does consumption. Consequently, investment variation is a disproportionate part of cyclical output variation. This is shown in Figure 3.

3.2 Inference drawn from these facts

Now why did economists looking at these facts conclude that they ruled out total factor productivity and other real shocks as being a significant contributor to business cycle fluctuations? Their reasoning is as follows. Leisure and consumption are normal goods. The evidence at that time was that the real wage was acyclical, which implies no cyclical substitution effects and leaves only the wealth effect. Therefore, in the boom when income is high, the quantity of leisure should be high, when in fact it is low. This logic is based on partial equilibrium reasoning, and the conclusion turned out to be wrong.

In the 1970s a number of interesting conjectures arose as to why the economy fluctuated as it does. Most were related to finding a propagation mechanism that resulted in Lucas's monetary surprise shocks having persistent real effects. With this theory, leisure moves countercyclically in conformity with observations. The deviations of output and employment from trend are not persistent with this theory, but in fact they are persistent. This initiated a search for some feature of reality that when introduced gives rise to persistent real effects. To put it another way, economists searched for what Frisch called a propagation mechanism for the effects of monetary surprises.

Taylor (1980) and Fischer (1977) provided empirical and theoretical evidence in support of their conjecture that staggered nominal wage contracting might

be the mechanism by which monetary shocks gave rise to persistent real effects on output and employment. Another conjectured mechanism of that era is the cost of changing nominal prices. In that era about the only people who argued that real shocks were the factor were Long and Plosser (1983). I say “in that era” because earlier, Wicksell (1907), Pigou (1927), and others held the view that real shocks were an important contribution to business cycles. My prior at the time we did the research for our “Time to Build” paper, and I think Finn’s prior as well, was that business cycle fluctuations were induced by nominal and not real shocks.

3.3 Macroeconomics and growth theory before the “Time to Build” paper

Macroeconomics of the 1970s largely ignored capital accumulation. Growth theory was concerned with the long-term movements in the economic aggregates, whereas macroeconomics was concerned with the short-term movements. Virtually no connection was made between the then-dormant growth theory and the dynamic equilibrium theories of business cycles. Probably the reason was that short-term movements in output are accounted for in large part by movements in the labor input, whereas long-term growth in living standards is accounted for by increases in the capital service input and in total factor productivity. All these variables are per working-age person.

Kydland and I decided to use the neoclassical growth model to study business cycle fluctuations in the summer of 1980. The basic theoretical framework we developed came to be called the real business cycle model. The term *real* does not mean that the framework can be used only to answer questions concerning the consequences of real shocks. The real business cycle model is equally applicable to addressing the consequences of monetary shocks. I will not be discussing these monetary applications in this address because Kydland will in his address. This is appropriate given that he and his collaborators, and not I, are leaders in the study of the consequences of monetary policy for business cycles.

3.4 The methodology

This model builds on the contributions of many economists, many of whom have been awarded the Nobel Prize. The importance of the contributions of Simon Kuznets and Richard Stone in developing the national income and product accounts cannot be overstated. These accounts reveal a set of growth facts, which led to Solow’s (1956) classical growth model, which Solow (1970) calibrated to the growth facts. This simple but elegant model accounts well for the secular behavior of the principal economic aggregates. With this model, however, labor supply is supplied inelastically and savings is behaviorally determined. There are people in the classical growth model economy, but they make no decisions. This is why I, motivated by Frisch’s Nobel address delivered here in 1969, refer to this model as the classical growth model.

The steps in Finn's and my methodology are as follows.

Step 1: Start with the Neoclassical Growth Model

Central to the neoclassical growth model is the Solow–Swan aggregate production function. As explained in Solow (1956, n. 7), the theory underlying the aggregate production function is a theory of the income side of the national accounts.³ With competitive factor and product markets and entry and exit of production units, factor claims against product exhaust product. In addition, output is maximized given the quantities of the factor inputs supplied.

The function F_t is the period t aggregate production function that specifies the output that is produced as a function of the inputs

$$(1) \quad c_t + x_t = y_t = F_t(k_t, l_t),$$

where c is consumption, x is investment, y is output, k is the capital service input, and l is the labor service input. One unit of capital provides one unit of capital services, and capital depreciates geometrically at rate δ . Thus,

$$(2) \quad k_{t+1} = (1 - \delta)k_t + x_t.$$

We also introduced a multi-period requirement for building new capacity because we thought it might be an important shock propagation mechanism.⁴

For the growth model to be neoclassical, the savings-investment and labor-leisure decisions must be decisions of the households. Finn and I introduced an *aggregate* or stand-in household with preferences ordered by the expected discounted value of utility flows from consumption and leisure; that is, the household maximizes the expected value of

$$(3) \quad \sum_{t=0}^{\infty} \beta^t u(c_t, 1-h_t),$$

where c is consumption and $1-h$ is leisure. The aggregation theory underlying this aggregate household is based in part on the first welfare theory, namely, that a competitive equilibrium maximized some weighted average of individual utilities.

³ For partial equilibrium models, this was recognized by Marshall and Wicksell at the end of the 19th century, but Solow saw it in the general equilibrium context.

⁴ Hansen (1985) shows that this feature of reality is not central to understanding business cycle fluctuations and is best abstracted from.

Previously, others had effectively endogenized the savings decision by analyzing the optimal growth path because, by the second welfare theorem, the optimal path is the competitive equilibrium path for this model.⁵ But in order for the model to be used to study business cycle fluctuations, the labor supply decision must be endogenized as well.⁶

Step 2: Modify the National Accounts to Be Consistent with the Theory

Prior to our work, macroeconomics was concerned with developing a theory of the national accounts statistics. Preferences and technology are the given, not the national accounts statistics. This means that we had to modify the national accounts to be consistent with the theoretical abstraction or model we used. The most important modification when studying business cycles is to treat consumer durable expenditures as an investment in the same way that expenditures on new housing and home improvement are treated as investments in the national accounts. Once this is done, services of consumer durables and consumer durable rental income must be imputed, in much the same way as is currently done for owner-occupied housing. This increases investment share of output and has consequences for the cyclical behavior of the economy. What led us to think about this issue is that consumer durable expenditures are highly variable, behaving very similarly to producer durable investments and not like consumer expenditures on nondurable goods and services.

Step 3: Restrict the Model to Be Consistent with the Growth Facts

The growth facts are that consumption and investment shares of output are roughly constant, as are labor and capital cost shares. All the variables and the real wage grow over time except for labor supply and the return on capital, which are roughly constant. This leads to a Cobb–Douglas production function. These facts also imply the constancy of the capital-output ratio and of the rental price of capital.

Two key growth facts are that the real wage and consumption grow at the same secular rate as does real output per capita, while labor supply displays no secular trend. This restricts the period utility function to be of the form

$$(4) \quad u(c, 1-h) = \frac{(c g(1-l))^{1-\sigma} - 1}{1-\sigma} .$$

⁵ Cass (1965) and Koopmans (1965) in deterministic situations establish the existence of an optimal path and characterize properties of this optimal path. Diamond (1965) studies the competitive equilibrium path in an economy with capital accumulation. In his economy, people live two periods. Brock and Mirman (1972) deal with the problem of optimal growth when there are stochastic shocks to the technology. These studies are in the nonquantitative theory tradition. Danthine and Donaldson (1981) compute the equilibrium process for the Brock and Mirman (1972) stochastic growth model.

⁶ Auerbach, Kotlikoff, and Skinner (1983) carry out a deterministic dynamic applied general equilibrium analysis with endogenous labor supply in which they evaluate tax policies.

We set $\sigma = 1$. This parameter was not calibrated to growth observations. We made this choice based on a variety of evidence. The principal evidence used is comparisons of the return on capital for fast- and slow-growing economies. Fortunately, it turned out that our findings are not sensitive to this parameter, because at the time of our work, this key economic parameter had not been tightly tied down.

With $\sigma = 1$, the above utility function is

$$(5) \quad \log c + g(1-l).$$

The nature of the g function matters. The growth facts do not tie down the elasticity of substitution between consumption and leisure, and this parameter turned out to be key for deriving the predictions of the growth model for business cycle fluctuations. Subsequently, this key parameter has been tied down.

Step 4: Introduce a Markovian Shock Process

We wanted something in our model economy that led to labor supply errors and something to propagate these errors. Here, by “labor supply errors” I mean the difference between the optimal labor supply decision given individuals’ information set and the decision that they would make if they observed the state of the economy without observation error. We introduced a total factor productivity shock that is independent over time and assumes that agents see the value of total factor productivity (TFP) with noise prior to making their labor supply decisions. We also introduced a second highly persistent autoregressive TFP shock. We introduced this shock because it is simple to do and we were curious to see what its consequences are. In order to use the Kalman filter, the two shocks and measurement errors are all normally distributed.

Step 5: Make a Linear Quadratic Approximation

The next step is to determine the steady state of the economy when the variances of the TFP shocks are zero. Then a linear quadratic economy is constructed, which has the same first two derivatives at the steady state. This linear quadratic economy displays the growth facts, and its equilibrium is easily computed. The behavior of this economy will be arbitrarily close to the economy we began with for sufficiently small variances of the two TFP shocks and the measurement errors. It turned out that it was extremely close even for variances far bigger than the ones we introduced.⁷

Step 6: Compute the Competitive Equilibrium Process

The next step is to compute the recursive competitive equilibrium stochastic process.

⁷Danthine and Donaldson (1981), who computed the exact equilibrium for the stochastic model using computationally intensive techniques, found this to be the case.

Step 7: Simulate the Model Economy

The equilibrium stochastic process is used to generate a time series realization of the model economy. If the number of observations in the period being considered is N , a time series of length significantly greater than N is generated and the last N observations considered. A longer time series is generated because we wanted a draw from the invariant distribution for the state of the economy as a starting point of the model's sample path.

Step 8: Examine the Key Business Cycle Statistics and Draw Scientific Inference

The last step is to compare the key business cycle statistics for the model and the actual economy. I emphasize that the identical statistics for the model and the actual economy are compared.

One important statistic is the standard deviation of the cyclical component of output. What we defined to be the cyclical component of output is first computed for the actual economy and the standard deviation determined. The identical procedure is followed for realizations of the equilibrium process of the model economy. This means the model is simulated to generate the time series of output and other series. Next the cyclical component of output is computed and its standard deviation determined. This is done many times so that the first two moments of the sampling distribution of the standard deviation of the model's cyclical output statistic can be determined.

If the sampling distribution of this statistic in question is concentrated about some number, this number relative to the statistic specifies how variable the economy would have been if TFP shocks were the only shocks. If the sampling distribution of this statistic is not concentrated, theory does not provide a precise accounting. But the sampling distribution is highly concentrated provided the number of quarterly observations is at least 100.

I emphasize that this is not a test in the sense of Neyman–Pearson statistical hypothesis tests, which are useful in the search for a model or law through induction. The way theory is tested is through successful use. The neoclassical growth model is tested theory.

4. USING THE METHODOLOGY IN BUSINESS CYCLE RESEARCH

Kydland and Prescott (1982) found, as reported in our paper “Time to Build and Aggregate Fluctuations,” that if elasticity of substitution of labor supply is 3 and TFP shocks are highly persistent and of the right magnitude, then business cycles are what the neoclassical growth model predicts. This includes the amplitude of fluctuation of output, the serial correlation properties of cyclical output, the relative variability of consumption and investment, the fact that capital stock peaks and bottoms out later than does output, the cyclical behavior of leisure, and the cyclical output accounting facts.

Subsequently, Prescott (1986) found that the shocks were highly persistent and the TFP shocks of the right magnitude. Conditional on a labor supply elasticity close to 3, TFP shocks are *the* major contributor to fluctuations in the period 1954–1981 in the United States.

This finding turned out to be highly robust. Greenwood, Hercowitz, and Huffman (1988) find that if, on average, TFP shocks are non-neutral with regard to consumption and investment, the conclusions hold. Rotemberg and Woodford (1995) introduce imperfect competition and show that the finding is overturned only if monopoly rents are far in excess of what they could be. With imperfect competition restricted to be consistent with labor cost share, Hornstein (1993) and Devereux, Head, and Lapham (1996) show that the importance of TFP shocks for business cycle fluctuations hardly changes. With the introduction of monopolistic competition, model-TFP shock variance is picked so that the model Solow-TFP variance matches the actual economy's Solow-TFP variance. In these monopolistic competitive worlds, Solow-TFP is a complex statistic and is not total factor productivity.

Investment in the model economy varies smoothly, as does aggregate investment in the actual economy. Investment at the plant level, however, is not smooth, and a natural question is whether this has consequences for modeling business cycles. Fisher and Hornstein (2000) find that having plants that make lumpy inventory investment in equilibrium does not change the estimates of the contribution of TFP shocks to fluctuations. For investment in plant and equipment, Thomas (2002) develops an economy that displays lumpy investment at the plant level. When calibrated to the growth facts and establishment investment statistics, the findings for business cycles using her abstraction are virtually the same as those using the neoclassical growth model.

Ríos-Rull (1995) uses a carefully calibrated overlapping generations model and finds that the estimated importance of TFP shocks for business cycle fluctuations does not change. Within this framework, Ríos-Rull (1994) then shuts down financial markets, so physical capital holdings is the only way to save. This extreme version of market incompleteness does not affect the estimate of the importance of TFP shocks. Introducing uninsurable idiosyncratic risk (see Krusell and Smith, 1998) does not affect the estimate either. Hansen and Prescott (2005) deal with capacity utilization constraints that are occasionally binding. With their introduction, the nature of the predictions for business cycles changes a little, but in a way that results in observations being in even closer conformity with theory.

Using this methodology, Danthine and Donaldson (1981) and Gomme and Greenwood (1995) investigate the consequences of various non-Walrasian features for business cycle fluctuations. There are interesting implications for relative variability of consumption for those with large capital ownership and those with no capital ownership.

Freeman and Kydland (2000) and Cooley and Hansen (1995) find that introducing money and a transaction technology does not alter the conclusion as to the importance of TFP shocks. Chari, Kehoe, and McGrattan (2000) find that nominal contracting does not either. They introduce staggered nominal contracting into the basic business cycle model and find that in such worlds, monetary shocks have effects that are persistent but too small to be an important contributor to business cycle fluctuations. In summary, introducing

monetary factors did not alter Finn's and my finding that TFP shocks are the major contributor to business cycle fluctuations in the United States in the 1954–1980 period we consider in our “Time to Build” paper.

But in all cases, to generate business cycles of the magnitude and nature observed, the aggregate labor supply elasticity must be 3.⁸ This attests to the robustness of the finding and focuses attention on this elasticity parameter. A variety of evidence that supports the number 3 had to be found before it was safe to conclude that the neoclassical growth model predicts business cycle fluctuations of the quantitative nature observed.

5. EVIDENCE THAT THE AGGREGATE ELASTICITY OF LABOR SUPPLY IS 3

A problem with the abstraction that many economists used to incorrectly conclude that labor supply is inelastic is that it has the prediction that everyone should make essentially the same percentage adjustment in hours worked. This is not the case. Over the business cycle, most of the variation in the aggregate number of hours worked is in the fraction of people working and not in the hours worked per worker. Looking at this observation, Rogerson (1984, 1988) studies a static world in which people either work a standard workweek or do not work. He shows that in this world, the aggregate elasticity of labor supply is infinite up to the point that the fraction employed is one.

Rogerson's aggregation result is every bit as important as the one giving rise to the aggregate production function.⁹ In the case of production technology, the nature of the aggregate production function in the empirically interesting cases is very different from that of the individual production units being aggregated. The same is true for the aggregate or a stand-in household's utility function in the empirically interesting case.

Aggregate hours of labor supplied to the market per working-age person, l , equals the product of the fraction employed, e , and hours per employee, h ; that is

$$(6) \quad l = eh.$$

If the principal margin of adjustment in l is the employment rate and not hours per employee, then aggregate labor supply elasticity will be much bigger than the elasticity of labor supply of the individuals being aggregated. Given that the principal margin of adjustment is e and not h , *the aggregate labor supply elasticity is much greater than the individual labor supply elasticity.*

⁸ For reviews of many more business cycles studies, see *Frontiers of Business Cycle Research* (Cooley 1995).

⁹ Rogerson uses the Prescott and Townsend (1984a, 1984b) lottery commodity point. This simplifies the analysis, but does not change the results because lottery equilibria are equivalent to Arrow–Debreu equilibria; see Kehoe, Levine, and Prescott (2002) and Prescott and Shell (2002).

Multiple margins determine e . Particularly important for males and single females is the fraction of potential working life that he or she works. This fraction is smaller if an individual retires earlier. For married females, Heckman and MaCurdy (1980) find that as the Rogerson theory predicts, their labor supply is highly elastic, with some estimates being as high as 10. For all, weeks of vacation and the number of holidays is another important margin of adjustment in labor supply.

Hansen (1985) derives the consequence of the Rogerson (1988) assumption for business cycle fluctuations and develops a stand-in household for a type. He finds that in worlds with labor indivisibility, fluctuations induced by TFP shocks alone give rise to fluctuations 10 percent greater than those observed. This indicates that aggregate labor supply elasticity is not infinite as in his model world.

Hansen's findings led Finn and me to introduce both margins of labor supply adjustment. We numerically found the only margin used is e with the standard production function. The natural question is why? Hornstein and Prescott (1993) answer this question.¹⁰ We permitted both margins to be adjusted. The key modification is that a worker's output y is

$$(7) \quad y = Ahk^\theta,$$

where h is the workweek length of this individual and k is the capital stock that this individual uses. A consequence is that payment per hour is an increasing function of h .

A key result is that all the growth facts hold for this modification of the neoclassical growth model. The important feature of this model is that capital used by one individual is not used by another in the period.

For the calibrated economy, the finding is that only the e margin is used except in extreme cases when all are employed. Only with $e = 1$ is $h > \bar{h}$, where \bar{h} is the endogenously determined "standard" week length. A question, then, is why do we see any variation in h ? My answer is that in worlds with "islands," some islands have $e = 1$ and $h > \bar{h}$ at a point in time. Here island i indicates occupation as well as location of work activity.

A question is: What is the real wage? The price of each workweek length is $w_{it}(h)$, where i denotes the island. If one naively assumes that an individual on island i is being paid real wage $w_{it}(h_{it})/h_{it}$ and regresses the logarithm of h_{it} on the log of this assumed wage, a small regression coefficient would be

¹⁰ Many years prior, Sherwin Rosen (1978) had pointed out that workweeks of different lengths are different commodities and their price is not, in general, proportional to the length of the workweek. Introducing this feature of reality into an applied dynamic general equilibrium model of business cycles did not occur until Kydland and Prescott (1991). Earlier, Hansen and Sargent (1988) had two workweek lengths, straight time and overtime.

obtained in this island version of the Hornstein–Prescott world. Many ran this regression for full-time male workers and obtained a small coefficient as predicted by theory, independent of whether the micro or Frischian labor supply elasticity is big or small.

Thus, a low value of this regression coefficient does not imply low elasticity of aggregate labor supply elasticity, which is what matters for the study of business cycles and the evaluation of tax policies. A low value does not even indicate a low micro labor supply elasticity, which is a statement about preferences only. I emphasize that *aggregate labor supply elasticity is a statement about both preferences and technology*. Only for empirically uninteresting cases are the micro and macro elasticities equal.

Evidence from Consequence of Tax Rates across Countries and across Time

Good statistics are available on labor supply and tax rates across the major advanced industrial countries. My measure of aggregate labor supply is aggregate hours worked in the market sector divided by the number of working-age people.

Given that the effect of the marginal effective tax rate on labor supply depends on this elasticity, and given that tax rates vary considerably, these observations provide an almost ideal test of whether the aggregate labor supply elasticity is 3. The set of countries that Prescott (2004) studied are the G-7 countries, which are the large advanced industrial countries. The differences in marginal tax rates and labor supply are large; Canada, Japan, and the United States have rates near 0.40, and France, Germany, and Italy near 0.60.¹¹ The prediction, based on an aggregate labor supply elasticity of 3, that Western Europeans will work one-third less than North Americans and Japanese is confirmed.¹² Added evidence for an aggregate elasticity of 3 is that it explains why labor supply in France and Germany was nearly 50 percent greater during the 1970–1974 period than it is today.

Observations on aggregate labor supply across countries and across time imply a labor supply elasticity near 3.

Recent Evidence from Major Contractions and Expansions

Additional evidence is provided by the study of recent major contractions. The finding is that the elasticity of labor supply must be near 3 to account for the behavior of the labor supply in each case. Three advanced industrial countries with good economic statistics suffered a 20 percent or more loss in

¹¹ See Prescott (2004).

¹² The preference ordering used has a constant elasticity of substitution between consumption and leisure, not between consumption and labor supplied to the market. The elasticity of labor supply for our stand-in household is $(1 - h)/h$, where h is the fraction of productive time allocated to the market. Given that h in Europe is smaller than one-fourth of the U.S. number, the elasticity of labor supply there is even greater than 3 in Europe.

output per capita relative to a 2 percent trend in the last quarter to the 20th century. The countries are Japan in the 1990s and New Zealand and Switzerland in the 1970s and 1980s. The behavior of labor supply during these extended periods of nonbalanced growth implies the same labor supply elasticity as do business cycle fluctuations.¹³

Life Cycle Labor Supply Evidence

Recently, Imai and Keene (2004) examined the life cycle pattern of male labor supply. Real payments per hour are hump-shaped, as are hours worked over the working lifetime. The percentage size of the hump is greater for real payment per hour than for hours worked. This led some to conclude that male labor supply is inelastic; that is, the elasticity is less than 1. Imai and Keene take into consideration the value of the skills that younger workers acquire on the job – that is, the human capital they receive. This is part of total compensation and should be included in the wage. When it is, the lifetime wage schedule is much flatter than life cycle labor supply. Imai and Keene's estimate is 3.7. If this estimate rather than 3 is used, it would not change business cycle findings significantly. Further, the real interest rate implied by their analysis is close to the average real return on capital obtained using the neoclassical growth model and the national accounts.

An important difference between what labor economists estimate and what macroeconomists estimate is that labor economists use a constant elasticity of substitution utility function on consumption and labor supply, whereas macroeconomists use a constant elasticity of substitution on consumption and leisure.

A problem with many labor economists' estimates is that they maintain the hypothesis that people are not in organizational settings that have a fixed workweek length. Fitzgerald (1998) introduces team production with both supervisors and workers. Equilibrium is characterized by a fixed workweek length. The hours worked is not a choice variable of individuals. The individual choice variable is whether or not to work for this organization or for some other organization. In this world when people are promoted from worker to supervisor, their wages increase, but no change in hours worked occurs. Under the incorrect maintained hypothesis, these observations would lead to the conclusion that labor supply is perfectly inelastic, even if it is in fact large.

To summarize, aggregate observations imply that the aggregate labor supply elasticity is large. Aggregation theory implies that whenever the principal margin of adjustment is the fraction employed and not hours per person employed, the aggregate labor supply elasticity is large. This finding is consistent with all the micro observations, so no conflict arises between micro and macro observations.

¹³ See the Kehoe and Prescott (2002) volume for a number of economic depression studies.

6. SIGNIFICANCE OF BUSINESS CYCLE RESEARCH

We learned that business cycle fluctuations are the optimal response to real shocks. The cost of a bad shock cannot be avoided, and policies that attempt to do so will be counterproductive, particularly if they reduce production efficiency. During the 1981 and current oil crises, I was pleased that policies were not instituted that adversely affected the economy by reducing production efficiency. This is in sharp contrast to the oil crisis in 1974 when, rather than letting the economy respond optimally to a bad shock so as to minimize its cost, policies were instituted that adversely affected production efficiency and depressed the economy much more than it would otherwise have been.

To summarize, concern has shifted away from business cycle fluctuations toward more important things. One important thing is setting up a good tax system. Finn's and my work sheds light on the most important economic parameter in the design of a tax system, the aggregate labor supply elasticity. In finding that technology shocks are important for fluctuations, our research program has been important in shifting the profession's attention to how economic institutions affect total factor productivity.

7. BEYOND BUSINESS CYCLE RESEARCH

The methodology that Finn and I developed and used to study business cycles is equally applicable to studying other phenomena. In this section I will briefly review three successful applications of this methodology and one very interesting open puzzle. While presenting evidence that the labor supply elasticity is 3, I already effectively reviewed one highly successful application – namely, my study assessing the role of taxes in accounting for the huge differences in labor supply across the advanced industrial countries and the huge fall in labor supply in Europe between the early 1970s and the mid-1990s.

Using the Methodology in the Stock Market Valuation Research

An interesting question is, why did the value of the stock market relative to GDP vary by a factor of 2.5 in the United States and 3 in the United Kingdom in the last half of the 20th century? Other variables display little secular variation relative to GDP, whether they are corporate after-tax profits or corporate physical capital relative to GDP.

Clearly the single sector neoclassical growth model does not suffice for studying the market value of corporate equity. The model must have both a corporate and noncorporate sector. Fortunately, the national accounts report the components of value added for the corporate sector as well as for government business, household business, and unincorporated business sectors. Various adjustments must be made to the accounts to bring them into conformity with the model, such as using producer prices for both inputs and outputs to the business sector.

An equilibrium relation develops when the market value of corporations is equal to the value of their productive assets. The capital accounts of the national accounts provide measures of the cost of replacing tangible capital.

But corporations also own large amounts of intangible capital, including organization capital, brand names, and patents, which also affect the market value of corporations. These assets cannot be ignored when determining what theory says the value of the stock market should be. This presents a problem for determining the fundamental value of the stock market – a problem that McGrattan and I solve (see McGrattan and Prescott, 2005a).

We find that the secular behavior of the value of the U.S. stock market is as theory predicts. What turns out to be important for the movement in the value of corporations relative to GDP are changes in tax and regulatory policies. If the tax rate on distributions by corporations is 50 percent rather than 0 percent, the value of corporations will be only half as large given the resource cost of their productive assets.

Our study uses a neoclassical growth model and connects the model to national income and product data, tax data, and sector balance sheet data. We submitted the paper to the *Review of Economic Studies*, a British journal. The editor rightfully insisted that we do the analysis for the U.K. stock market as well as for the U.S. stock market. We were nervous as to what theory and measurement would say and were happy when we found that the behavior of the value of the U.K. stock market was also in conformity to theory. Here is an example of the power of the macroeconomic methodology that Finn and I developed.

The excessive volatility of stock prices remains. Indeed, our study strengthens this puzzle. Stocks of productive capital vary little from year to year, whereas stock prices sometimes vary a lot. I am sure this volatility puzzle will, in the not too distant future, be resolved by some imaginative neoclassical economist. However, resolving the secular movement puzzle is progress.

This example illustrates how macroeconomics has changed as a result of the methodology that Finn and I pioneered. It is now that branch of economics in which applied dynamic equilibrium tools are used to study aggregate phenomena. The study of each of these aggregate phenomena is unified under one theory. This unification attests to the maturity of economic science when it comes to studying dynamic aggregate phenomena.

Using the Methodology to Study the Great U.S. Depression

The welfare gains from eliminating business cycles are small or negative. The welfare gains from eliminating depression and creating growth miracles are large. Cole and Ohanian (1999) broke a taboo and used the neoclassical growth model to study the Great U.S. Depression. One of their particularly interesting findings is that labor supply on a per adult basis in the 1935–1939 period was 25 percent below what it was before the Depression. Recently, Cole and Ohanian (2004) showed how New Deal cartelization could very well have been the reason for the low labor supply using neoclassical economics. The rapid recovery of the U.S. economy subsequent to the abandonment of these cartelization policies supports their theory.

Japan's Lost Decade of Growth

A more recent example is Japan's lost decade of growth, which was the 1992–2001 decade. Hayashi and Prescott (2002), treating TFP as exogenous, find that the neoclassical growth model predicts well the path of the principal aggregates. In particular it quantitatively predicts the large capital deepening and the associated fall in the return on capital. It quantitatively predicts the behavior of labor supply as well, which is further evidence for the high labor elasticity of labor supply.

A Business Cycle Puzzle

An economic boom in the United States began with an expansion relative to trend in early 1996 and continued to the fourth quarter of 1999. Then, a contraction set in and continued until the third quarter to 2001. At the peak, detrended GDP per working-age person was 4 percent above trend and labor supply 5 percent above average. None of the obvious candidates for the high labor supply were operating. There was no war with temporarily high public consumption that was debt financed; tax rates were not low; TFP measured in the standard way was not high; and there was no monetary surprise that would give rise to high labor supply. This is why I say this boom is a puzzle for the neoclassical growth model.

Why did people supply so much labor in this boom period? The work of McGrattan and Prescott (2005a), which determines the quantitative predictions of theory for the value of the stock markets, suggests an answer. The problem is one of *measurement*. During this period (see McGrattan and Prescott, 2005b), there is evidence that unmeasured investment was high, as was unmeasured compensation. Therefore, output and productivity were higher than the standard statistics indicate. The measurement problem is to come up with estimates of this expensed investment. With these improved measurements of economic activity, theory can be used to determine whether or not the puzzle has been solved.

This example illustrates the unified nature of aggregate economics today. The real business cycle model was extended and used to understand the behavior of the stock market, and that extended model in turn is now being used to resolve a business cycle puzzle.

8. RAGNAR FRISCH'S VISION REALIZED

I conclude this address with an ode to Frisch, who was awarded the first Nobel Prize in Economics in 1969. Frisch's Nobel address is entitled "From Utopian Theory to Practical Applications: The Case of Econometrics" (1970). He is the father of quantitative neoclassical economics, which is what he is referring to by the word *econometrics* in the title.¹⁴

¹⁴Frisch (1970, p. 12) reports that the English mathematician and economist Jevons (1835–1882) dreamed that we would be able to quantify neoclassical economics.

Prior to Frisch's creating the Econometric Society in 1930 and launching *Econometrica* in 1933, neoclassical economists did little to verify their theoretical results by statistical observations. Frisch writes in his Nobel address that the reason was in part the poor quality of statistics then available and in part that neoclassical theory was not developed with systematic verification in view. The American Institutionalists and German Historical schools pointed this out and advocated letting the facts speak for themselves. The impact of these schools on economic thought was minimal. To quote Frisch, "Facts that speak for themselves, talk in a very naive language" (1970, p. 16). Now theory derives its concepts from measurement, and in turn theory dictates new measurement. The latter is what McGrattan and I are currently doing to resolve the puzzle of why U.S. employment was so high at the end of the 1990s.

In the 1960s Frisch was frustrated by the lack of progress in his quest to making neoclassical economics quantitative and referred to much of what was being done then as "playometrics." It is a little unfair to criticize those studying business cycles at that time for not using the full discipline of neoclassical economics. All the needed tools were not yet part of the economist's tool kit. Some of these tools that are crucial to the study of business cycles are Lindal's extension of general equilibrium theory to dynamic environments; Savage's statistical decision theory as uncertainty is central to business cycles; Arrow and Debreu's extension of general equilibrium theory to environments with uncertainty; Blackwell's development of recursive methods which are needed in computation and in representation of a dynamic stochastic equilibrium; Lucas and Prescott's development of recursive competitive equilibrium theory;¹⁵ and, of course, the computer.

Particularly noteworthy is Lucas's role in the macroeconomic revolution. In the very late 1960s and early 1970s he revolutionized macroeconomics by taking the position that neoclassical economics should be used to study business cycles. Others had dreamed of doing it, but Lucas actually figured out ways to do it. In his 1972 paper "Expectations and the Neutrality of Money," he creates and analyzes a dynamic stochastic neoclassical model that displays the Phillips curve, which is a key equation in the system-of-equations macro models. I can think of no paper in economics as important as this one. The key prediction based upon this theoretical analysis – namely, that there is no exploitable trade-off between inflation and employment – was confirmed in the 1970s when attempts were made to exploit the then perceived trade-off.

But Lucas's work is not *quantitative* dynamic general equilibrium, and only 10 years later did Finn and I figure out how to quantitatively derive the implications of theory and measurement for business cycle fluctuations using the full discipline of dynamic stochastic general equilibrium theory and

¹⁵This was further developed in Prescott and Mehra (1980). The published version of "Investment under Uncertainty" did not include the section formally defining the recursive equilibrium with policy and value functions depending on both an individual firm's capacity and the industry capacity and was an industry equilibrium analysis.

national accounts statistics. That we have learned that business cycles of the quantitative nature observed are what theory predicts is testimony to the grand research program of Ragnar Frisch and to the vision and creative genius of Robert Lucas.

On nearly every dimension I am in agreement with what Frisch advocated in his Nobel Prize address, but on one dimension I am not. Like Frisch, I am a fervent believer in the democratic process. The dimension on which I disagree is how economists and policy makers should interact. His view is that the democratic political process should determine the objective, and economists should then determine the best policy given this objective. My view is that economists should educate the people so that they can evaluate macroeconomic policy rules and that the people, through their elective representatives, should pick the policy rule. I emphasize that Finn and my “Rules Rather than Discretion” paper finds that public debate should be over rules and that rules should be changed only infrequently, with a lag to mitigate the time consistency problem.

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