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Real Business Cycle Models: Past, Present and Future

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I. Introduction

Finn Kydland and Edward Prescott introduced not one, but three, revolutionary ideas in their 1982 paper, "Time to Build and Aggregate Fluctuations". The first idea, which builds on prior work by Lucas and Prescott (1971), is that business cycles can be studied using dynamic general equilibrium models. These models feature atomistic agents who operate in competitive markets and form rational expectations about the future. The second idea is that it is possible to unify business cycle and growth theory by insisting that business cycle models should be consistent with the empirical regularities of long-run growth. The third idea is that we can go way beyond the qualitative comparison of model properties with stylized facts that dominated theoretical work on macroeconomics until 1982. We can calibrate models with parameters drawn, to as far an extent as possible, from microeconomic studies and long-run properties of the economy, and we can use these calibrated models to generate artificial data that can be compared with actual data.

It is not surprising that a paper with so many new ideas has shaped the macroeconomics research agenda of the last two decades. The wave of models that first followed Kydland and Prescott's (1982) work were referred to as "real business cycle" models because of their emphasis on the role of real shocks, particularly technology shocks, in driving business fluctuations. But real business cycle (RBC) models also became a point of departure for many theories in which technology shocks do not play a central role.

In addition, RBC-based models came to be widely used as laboratories for policy analysis in general and for the study of optimal fiscal and monetary

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policy in particular.[1] These policy applications reflected the fact that RBC models represented an important step in meeting the challenge set forth by Robert Lucas (1980) when he wrote:

> "One of the functions of theoretical economics is to provide fully articulated, artificial economic systems that can serve as laboratories in which policies that would be prohibitively expensive to experiment with in actual economies can be tested out at much lower cost. [. . .] Our task as I see it [. . .] is to write a FORTRAN program that will accept specific economic policy rules as 'input' and will generate as 'output' statistics describing the operating characteristics of time series we care about, which are predicted to result from these policies."

In the next section I briefly review the properties of RBC models. It would have been easy to extend this review into a full-blown survey of the literature. But I resist this temptation for two reasons. First, King and Rebelo (1999) already contains a discussion of the RBC literature. Second, and more important, the best way to celebrate RBC models is not to revel in their past, but to consider their future. So I devote Section III to some of the challenges that face the theoretical edifice that has built up on the foundations laid by Kydland and Prescott in 1982. Section IV concludes.

II. Real Business Cycles

Kydland and Prescott (1982) judge their model by its ability to replicate the main statistical features of U.S. business cycles. These features are summarized in Hodrick and Prescott (1980) and revisited in Kydland and Prescott (1990). Hodrick and Prescott detrend U.S. macro time series with what became known as the "HP filter". They then compute standard deviations, correlations and serial correlations of the major macroeconomic aggregates.

Macroeconomists know their main findings by heart. Investment is about three times more volatile than output, and non-durables consumption is less volatile than output. Total hours worked and output have similar volatility. Almost all macroeconomic variables are strongly procyclical, i.e., they show a strong contemporaneous correlation with output.[2] Finally, macroeconomic variables show substantial persistence. If output is high relative to trend in this quarter, it is likely to continue above trend in the next quarter.

[1] See Chari and Kehoe (1999) for a review of the literature on optimal fiscal and monetary policy in RBC models.

[2] A notable exception is the trade balance which is countercyclical; see Baxter and Crucini (1993).

Kydland and Prescott (1982) find that simulated data from their model show the same patterns of volatility, persistence and comovement as are present in U.S. data. This finding is particularly surprising, because the model abstracts from monetary policy, which economists such as Friedman (1968) consider an important element of business fluctuations.

Instead of reproducing the familiar table of standard deviations and correlations based on simulated data, I adopt an alternative strategy to illustrate the performance of a basic RBC model. This strategy is similar to that used by the Business Cycle Dating Committee of the National Bureau of Economic Research (NBER) to compare different recessions, as reported in Hall *et al.* (2003), and the methods used by Burns and Mitchell (1946) in their pioneer study of the properties of U.S. business cycles.

I start by simulating the model studied in King, Plosser and Rebelo (1988) for 5,000 periods, using the calibration in Table 2, column 4, of that paper. This model is a simplified version of Kydland and Prescott (1982). It eliminates features that are not central to their main results: time-to-build in investment, non-separable utility in leisure, and technology shocks that include both a permanent and a transitory component. I detrend the simulated data with the HP filter. I identify recessions as periods in which output is below the HP trend for at least three consecutive quarters.[3]

Figure 1 shows the average recession generated by the model. All variables are represented as deviations from their value in the quarter in which the recession starts, which I call period zero. This figure shows that the model reproduces the first-order features of U.S. business cycles. Consumption, investment and hours worked are all procyclical. Consumption is less volatile than output, investment is much more volatile than output, and hours worked are only slightly less volatile than output. All variables are persistent. One new piece of information I obtain from Figure 1 is that recessions in the model last for about one year, just as in the U.S. data.

III. Open Questions in Business Cycle Research

I begin by briefly noting two well-known challenges to RBC models. The first is explaining the behavior of asset prices. The second is understanding

[3] Interestingly, applying this method to U.S. data produces recession dates that are similar to those chosen by the NBER dating committee. The NBER dates for the beginning of a recession and the dates obtained with the HP procedure (indicated in parentheses) are as follows: 1948-IV (1949-I), 1953-II (1953-IV), 1960-II (1960-III), 1969-IV (1970-I), 1973-III (1974-III), 1981-III (1981-IV), 1990-III (1990-IV) and 2001-I (2001-III). The NBER dates include 1980-I, which is not selected by the HP procedure. In addition, the HP procedure includes three additional recessions starting in 1962-III, 1986-IV and 1995-I. None of the latter episodes involved a fall in output.

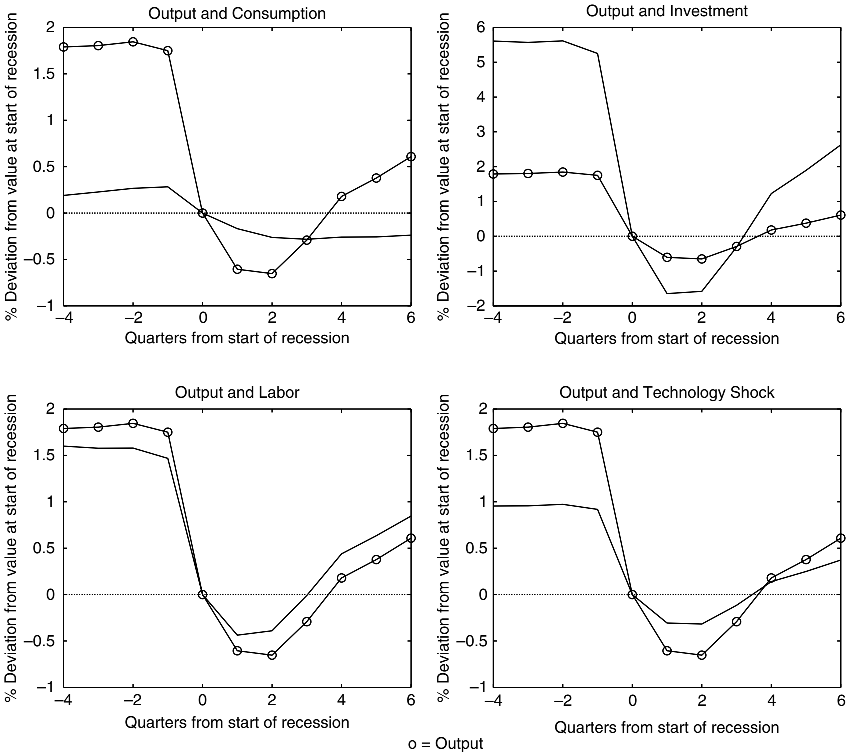

Fig. 1. An average recession in a real business cycle model

the Great Depression. I then discuss research on the causes of business cycles, the role of labor markets, and explanations for the strong patterns of comovement across different industries.

The Behavior of Asset Prices

Real business cycle models are arguably successful at mimicking the cyclical behavior of macroeconomic quantities. However, Mehra and Prescott (1985) show that utility specifications common in RBC models have counterfactual implications for asset prices. These utility specifications are not consistent with the difference between the average return to stocks and bonds. This "equity premium puzzle" has generated a voluminous literature, recently reviewed by Mehra and Prescott (2003).

Although a generally accepted resolution of the equity premium puzzle is currently not available, many researchers view the introduction of habit formation as an important step in addressing some of the first-order dimensions of the puzzle. Lucas (1978)-style endowment models, in which preferences feature simple forms of habit formation, are consistent with the difference in average returns between stocks and bonds. However, these models generate bond yields that are too volatile relative to the data.[4]

Boldrin, Christiano and Fisher (2001) show that simply introducing habit formation into a standard RBC model does not resolve the equity premium puzzle. Fluctuations in the returns to equity are very small, because the supply of capital is infinitely elastic. Habit formation introduces a strong desire for smooth consumption paths, but these smooth paths can be achieved without generating fluctuations in equity returns. Boldrin *et al.* (2001) modify the basic RBC model to reduce the elasticity of capital supply. In their model, investment and consumption goods are produced in different sectors and there are frictions to the reallocation of capital and labor across sectors. As a result, the desire for smooth consumption introduced by habit formation generates volatile equity returns and a large equity premium.

What Caused the Great Depression?

The Great Depression was the most important macroeconomic event of the twentieth century. Many economists interpret the large output decline, stock market crash and financial crisis that occurred between 1929 and 1933 as a massive failure of market forces that could have been prevented, had the government played a larger role in the economy. The dramatic increase in government spending as a fraction of GDP that we have seen since the 1930s is partly a policy response to the Great Depression.

In retrospect, it seems plausible that the Great Depression resulted from an unusual combination of bad shocks compounded by bad policy. The list of shocks includes large drops in the world price of agricultural goods, instability in the financial system and the worst drought ever recorded. Bad policy was in abundant supply. The central bank failed to serve as lender of last resort as bank runs forced many U.S. banks to close. Monetary policy was contractionary in the midst of the recession. The Smoot–Hawley tariff of 1930, introduced to protect farmers from declines in world agricultural prices, sparked a bitter tariff war that crippled international trade. The federal government introduced a massive tax increase through the Revenue Act of 1932. Competition in both product and labor markets was undermined by government policies that permitted industry to collude and increased the bargaining power of unions. Using rudimentary data sources to sort out the

[4] Early proponents of habit formation as a solution to the equity premium puzzle include Sundaresan (1989), Abel (1990) and Constantinides (1990). See Campbell and Cochrane (1999) for a recent discussion of the role of habit formation in consumption-based asset pricing models.

effects of these different shocks and different policies is a daunting task, but significant progress is being made.[5]

What Causes Business Cycles?

One of the most difficult questions in macroeconomics asks, what are the shocks that cause business fluctuations? Long-standing suspects are monetary, fiscal and oil price shocks. To this list Prescott (1986) adds technology shocks, and argues that they "account for more than half the fluctuations in the postwar period with a best point estimate near 75%".

The idea that technology shocks are the central driver of business cycles is controversial. Prescott (1986) computes total factor productivity (TFP) and treats it as a measure of exogenous technology shocks. However, there are reasons to distrust TFP as a measure of true shocks to technology. TFP can be forecast using military spending, as in Hall (1988), or monetary policy indicators, as in Evans (1992), both of which are variables that are unlikely to affect the rate of technical progress. This evidence suggests that TFP, as computed by Prescott, is not a pure exogenous shock, but has some endogenous components. Variable capital utilization, considered by Basu (1996) and Burnside, Eichenbaum and Rebelo (1996), variability in labor effort, considered by Burnside, Eichenbaum and Rebelo (1993), and changes in markup rates, considered by Jaimovich (2004a), drive important wedges between TFP and true technology shocks. These wedges imply that the magnitude of true technology shocks is likely to be much smaller than that of the TFP shocks used by Prescott.

Burnside and Eichenbaum (1996), King and Rebelo (1999) and Jaimovich (2004a) argue that the fact that true technology shocks are smaller than TFP shocks does not imply that technology shocks are unimportant. Introducing mechanisms such as capacity utilization and markup variation in RBC models has two effects. First, these mechanisms make true technology shocks less volatile than TFP. Second, they significantly amplify the effects of technology shocks. This amplification allows models with these mechanisms to generate output volatility similar to the data with much smaller technology shocks.

Another controversial aspect of RBC models is the role of technology shocks in generating recessions. The NBER Business Cycle Dating Committee defines a recession as "a significant decline in economic activity spread across the economy, lasting more than a few months, normally visible in real GDP, real income, employment, industrial production, and

[5] See Christiano, Motto and Rostagno (2005), Cole and Ohanian (1999, 2004) and the January 2002 issue of the *Review of Economic Dynamics* and the references therein.

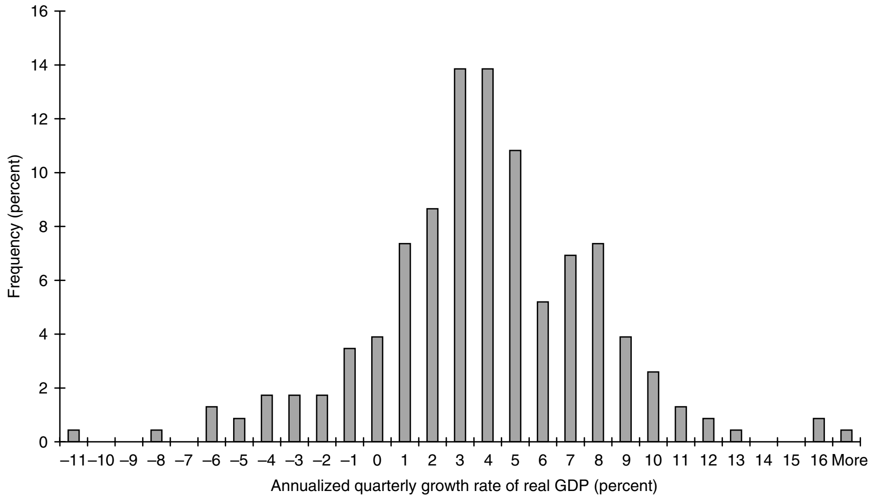

Fig. 2. Histogram of quarterly growth rates (1947-I to 2004-IV)

wholesale–retail sales"; cf. Hall *et al*. (2003). Figure 2 shows a histogram of annualized quarterly growth rates of U.S. real GDP. In absolute terms, output fell in 15 percent of the quarters between 1947 and 2005. Most RBC models require declines in TFP in order to replicate the declines in output observed in the data.[6] Macroeconomists generally agree that expansions in output, at least in the medium to long run, are driven by TFP increases that derive from technical progress. In contrast, the notion that recessions are caused by TFP declines meets with substantial skepticism because, interpreted literally, it means that recessions are times of technological regress.

Gali (1999) has fueled the debate on the importance of technology shocks as a business cycle impulse. Gali uses a structural VAR that he identifies by assuming that technology shocks are the only source of long-run changes in labor productivity. He finds that in the short run, hours worked fall in response to a positive shock to technology. This finding clearly contradicts the implications of basic RBC models. King *et al*. (1988) and King (1991) discuss in detail the property that positive technology shocks raise hours worked in RBC models. Gali's results have sparked an animated, ongoing debate. Christiano, Eichenbaum and Vigfusson (2003) find that Gali's results are not robust to specifying the VAR in terms of the level, as opposed to the first-difference, of hours worked. Chari, Kehoe and McGrattan (2004)

[6] One exception is the model proposed in King and Rebelo (1999), which minimizes the need for TFP declines in generating recessions. This model requires strong amplification properties that result from a highly elastic supply of labor and utilization of capital.

show that Gali's findings can be the result of misspecification.[7] Basu, Fernald and Kimball (1999) and Francis and Ramey (2001) complement Gali's results. They find them robust to using different data and VAR specifications.

Alternatives to Technology Shocks

The debate on the role of technology shocks in business fluctuations has influenced and inspired research on models in which technology shocks are either less important or play no role at all. Generally, these lines of research have been strongly influenced by the methods and ideas developed in the RBC literature. In fact, many of these alternative theories take the basic RBC model as their point of departure.

Oil Shocks. Movements in oil and energy prices are loosely associated with U.S. recessions; see Barsky and Killian (2004) for a recent discussion. Kim and Loungani (1992), Rotemberg and Woodford (1996) and Finn (2000) have studied the effects of energy price shocks in RBC models. These shocks improve the performance of RBC models, but they are not a major cause of output fluctuations. Although energy prices are highly volatile, energy costs are too small as a fraction of value added for changes in energy prices to have a major impact on economic activity.

Fiscal Shocks. Christiano and Eichenbaum (1992), Baxter and King (1993), Braun (1994) and McGrattan (1994), among others, have studied the effects of tax rate and government spending shocks in RBC models. These fiscal shocks improve the ability of RBC models to replicate both the variability of consumption and hours worked, and the low correlation between hours worked and average labor productivity. Fiscal shocks also increase the volatility of output generated by RBC models. However, there is not enough cyclical variation in tax rates and government spending for fiscal shocks to be a major source of business fluctuations.

While cyclical movements in government spending are small, periods of war are characterized by large, temporary increases in government spending. Researchers such as Ohanian (1997) show that RBC models can account for the main macroeconomic features of war episodes: a moderate decline in consumption, a large decline in investment and an increase in hours worked. These features emerge naturally in an RBC model in which government spending is financed by lump-sum taxes. Additional government spending has to be—sooner or later—financed by taxes. Household wealth declines

[7] See Gali and Rabanal (2005) for a discussion of some of the misspecification issues.

due to the increase in the present value of household tax liabilities. In response to this decline, households reduce their consumption and increase the number of hours they work, i.e., reduce their leisure. This increase in hours worked produces a moderate increase in output. Since the momentary marginal utility of consumption is decreasing, households prefer to pay for the war-related taxes by reducing consumption both today and in the future. Given that the reduction in consumption today plus the expansion in output are generally smaller than the government spending increase, there is a decline in investment. Cooley and Ohanian (1997) use an RBC model to compare the welfare implications of different strategies of war financing. Ramey and Shapiro (1998) consider the effects of changes in the composition of government spending. Burnside, Eichenbaum and Fisher (2004) study the effects of large temporary increases in government spending in the presence of distortionary taxation.

Investment-specific Technical Change. One natural alternative to technology shocks is investment-specific technological change. In standard RBC models, a positive technology shock makes both labor and existing capital more productive. In contrast, investment-specific technical progress has no impact on the productivity of old capital goods. Rather, it makes new capital goods more productive or less expensive, thereby raising the real return to investment.

We can measure the pace of investment-specific technological change using the relative price of investment goods in terms of consumption goods. According to data constructed by Gordon (1990), this relative price has declined dramatically in the past 40 years. Based on this observation, Greenwood, Hercowitz and Krusell (1997) use growth accounting methods to argue that 60 percent of the postwar growth in output per man-hour is due to investment-specific technological change. Using a VAR identified by long-run restrictions, Fisher (2003) finds that investment-specific technological change accounts for 50 percent of the variation in hours worked and 40 percent of the variation in output. In contrast, he finds that technology shocks account for less than 10 percent of the variation in either output or hours. Starting with Greenwood, Hercowitz and Krusell (2000), investment-specific technical change has become a standard shock included in RBC models.

Monetary Models. A great many studies explore the role of monetary shocks in RBC models that are extended to include additional real elements as well as nominal frictions.[8] Researchers such as Bernanke, Gertler and Gilchrist (1999) emphasize the role of credit frictions in influencing the response of

[8] See, for example, Dotsey, King and Wolman (1999), Altig, Christiano, Eichenbaum and Lindé (2004) and Smets and Wouters (2003). Clarida, Gali and Gertler (1999) and Christiano, Eichenbaum and Evans (1999) provide reviews of this literature.

the economy to both technology and monetary shocks. Another important real element is monopolistic competition, modeled along the lines of Dixit and Stiglitz (1977). In basic RBC models, firms and workers are price takers in perfectly competitive markets. In this perfectly competitive environment, it is not meaningful to think of firms as choosing prices or workers as choosing wages. Introducing monopolistic competition in product and labor markets gives firms and workers non-trivial pricing decisions.

The most important nominal frictions introduced in RBC-based monetary models are sticky prices and wages. In these models, prices are set by firms that commit to supplying goods at the posted prices, and wages are set by workers who commit to supplying labor at the posted wages. Prices and wages can only be changed periodically or at a cost. Firms and workers are forward looking; in setting prices and wages, they take into account that it can be too costly, or simply impossible, to change prices and wages in the near future.

This new generation of RBC-based monetary models can generate impulse responses to a monetary shock that are similar to the responses estimated using VAR techniques. In many of these models, technology shocks continue to be important, but monetary forces play a significant role in shaping the economy's response to technology shocks. In fact, both Altig *et al*. (2004) and Gali, Lopez-Salido and Valles (2004) find that in their models, a large short-run expansionary impact of a technology shock requires that monetary policy be accommodative.

Multiple Equilibrium Models. Many papers examine models that display multiple rational expectations equilibria. Early research on multiple equilibrium relied heavily on overlapping-generations models, partly because these models can often be studied without resorting to numerical methods. In contrast, the most recent work on multiple equilibrium, discussed in Farmer (1999), takes the basic RBC model as a point of departure and searches for the most plausible modifications that generate multiple equilibrium.

In basic RBC models, we can compute the competitive equilibrium as a solution to a concave planning problem. This problem has a unique solution, and so the competitive equilibrium is also unique. When we introduce features such as externalities, increasing returns to scale, or monopolistic competition, we can no longer compute the competitive equilibrium by solving a concave planning problem. Therefore, these features open the door to the possibility of multiple equilibria. Early versions of RBC-based multiple equilibrium models required implausibly high markups or large increasing returns to scale. However, there is a recent vintage of multiple equilibrium models that use more plausible calibrations; see, for example, Wen (1998a), Benhabib and Wen (2003) and Jaimovich (2004b).

Multiple equilibrium models have two attractive features. First, since beliefs are self-fulfilling, belief shocks can generate business cycles. If agents become pessimistic and think that the economy is going into a recession, the economy does indeed slow down. Second, multiple equilibrium models tend to have strong internal persistence, so such models do not need serially correlated shocks to generate persistent macroeconomic time series. Starting with a model that has a unique equilibrium and introducing multiplicity means reducing the absolute value of characteristic roots from above one to below one. Roots that switch from outside to inside the unit circle generally assume absolute values close to one, thus generating large internal persistence.

The strong internal persistence mechanisms of multiple equilibrium models are a clear advantage *vis-à-vis* standard RBC models. Although there are exceptions, such as the model proposed in Wen (1998b), most RBC models have weak internal persistence; see Cogley and Nason (1995) for a discussion. Figure 1 shows that the dynamics of different variables resemble the dynamics of the technology shock. Watson (1993) shows that as a result of weak internal persistence, basic RBC models fail to match the properties of the spectral density of major macroeconomic aggregates.

An important difficulty with the current generation of multiple equilibrium models is that they require beliefs to be volatile, but coordinated across agents. Agents often have to change their views about the future, but do so in a coordinated manner. This interest in beliefs has given rise to a literature, surveyed by Evans and Honkapohja (2001), that studies the process by which agents learn about the economic environment and form their expectations about the future.

Endogenous Business Cycles. The literature on "endogenous business cycles" studies models that generate business fluctuations, but without relying on exogenous shocks. Fluctuations result from complicated deterministic dynamics. Boldrin and Woodford (1990) note that since many of these models are based on the neoclassical growth model, they have the same basic structure as RBC models. Reichlin (1997) stresses two difficulties with this line of research. The first is that perfect foresight paths are extremely complex, thereby raising questions as to the plausibility of the perfect foresight assumption. The second is that models with determinist cycles often exhibit multiple equilibria which make them susceptible to the influence of belief shocks.

Other Lines of Research. I finish by describing two promising lines of research that are still in their early stages. The first line, discussed by Cochrane (1994), explores the possibility that "news shocks" may be important drivers of business cycles. Suppose that agents hear about a new technology, such as the internet, that will be available in the future and which is likely to have a significant impact on future productivity. Does this news generate an expansion today? Suppose that later on, the impact of this technology is found to be smaller than previously expected. Does this cause a recession? Beaudry and Portier (2004) show that standard RBC models cannot generate comovement between consumption and investment in response to news about future productivity. Future increases in productivity raise the real rate of return to investing and, at the same time, generate a positive wealth effect. If the wealth effect dominates, consumption and leisure rise, and hours worked and output fall. Since consumption rises and output falls, investment has to fall. If the real rate of return effect dominates, which happens for a high elasticity of intertemporal substitution, then investment and hours worked rise. However, in this case, output does not increase sufficiently to accommodate the rise in investment so consumption falls. Beaudry and Portier take an important first step in proposing a model that generates the right comovement in response to news about future increases in productivity. This model requires strong complementarity between durables and non-durables consumption, and abstracts from capital as an input into the production of investment goods. Producing alternatives to the Beaudry and Portier model is an interesting challenge to future research.

The second line of research studies the details of the innovation process and its impact on TFP. Comin and Gertler (2004) extend an RBC model to incorporate endogenous changes in TFP and in the price of capital result from research and development. Although they focus on medium-run cycles, their analysis is likely to have implications at higher frequencies. More generally, research on the adoption and diffusion of new technologies is likely to be important in understanding economic expansions.

Labor Markets

Most business cycle models require high elasticities of labor supply to generate fluctuations in aggregate variables of the magnitude that we observe in the data. In RBC models, these high elasticities are necessary to match the high variability of hours worked, along with the low variability of real wage rates or labor productivity. In monetary models, high labor supply elasticities are required to keep marginal costs flat and reduce the incentives for firms to change prices in response to a monetary shock. Multiple equilibrium models also rely on high elasticities of labor supply. If agents believe the economy is entering a period of expansion, the rate of return on investment must rise to justify the high level of investment necessary for beliefs to be self-fulfilling. This rise in returns on investment is more likely to occur if additional workers can be employed without a substantial increase in real wage rates.

Microeconomic studies estimate that the elasticity of labor supply is low. These estimates have motivated several authors to propose mechanisms that make a high aggregate elasticity of labor supply compatible with low labor supply elasticities for individual workers. The most widely used mechanism of this kind was proposed by Rogerson (1988) and implemented by Hansen (1985) in an RBC model. In the Hansen–Rogerson model, labor is indivisible, so workers have to choose between working full time or not working at all. Rogerson shows that this model displays a very high aggregate elasticity of labor supply that is independent of the labor supply elasticity of individual workers. This property results from the fact that, in the model, all variation in hours worked comes from the extensive margin, i.e., from workers moving in and out of the labor force. The elasticity of labor supply of an individual worker (i.e., the answer to the question "if your wage increased by 1 percent, how many more hours would you choose to work?") is irrelevant, because the number of hours worked is not a choice variable.

In RBC-based monetary models, sticky wages are often used to generate a high elasticity of labor supply. In sticky wage models, nominal wages only change sporadically and workers commit to supplying labor at the posted wages. In the short run, firms can employ more hours without paying higher wage rates. But when firms do so, workers are off their labor supply schedule, working more hours than they would like, given the wage they are being paid. Consequently, both the worker and the firm can be better off by renegotiating toward an efficient level of hours worked; see Barro (1977) and Hall (2005) for a discussion. More generally, sticky wage models raise the question of whether wage rates are allocational over the business cycle. Can firms really employ workers for as many hours as they see fit at the going nominal wage rate?

Hall (2005) proposes a matching model in which sticky wages can be an equilibrium outcome. He exploits the fact that in matching models there is a surplus to be shared between the worker and the firm. The conventional assumption in the literature is that this surplus is divided by a process of Nash bargaining. Instead, Hall assumes that the surplus is allocated by keeping the nominal wage constant. In his model, wages are sticky as long as the nominal wage falls within the bargaining set. However, there are no opportunities to improve the position of either the firm or the worker by renegotiating the number of hours worked after a shock.

Most business cycle models adopt a rudimentary description of the labor market. Firms hire workers in competitive spot labor markets and there is no unemployment. The Hansen–Rogerson model does generate unemployment. However, one unattractive feature of this model is that participation in the labor force is dictated by a lottery that makes the choice between working and not working convex.

Two important research topics in the interface between macroeconomics and labor economics are understanding the role of wages and the dynamics of unemployment. Macroeconomists have made significant progress on the latter topic. Search and matching models, such as the one proposed by Mortensen and Pissarides (1994), have emerged as a framework that is suitable for understanding not only the dynamics of unemployment, but also the properties of vacancies and of flows in and out of the labor force. Merz (1995), Andolfatto (1996), Alvarez and Veracierto (2000), Den Haan, Ramey and Watson (2000), Gomes, Greenwood and Rebelo (2001) and others have incorporated search into RBC models. However, as discussed by Shimer (2005), there is still work to be done on producing a model that can replicate the patterns of comovement and volatility of unemployment, vacancies, wages and average labor productivity present in U.S. data.

What Explains Business Cycle Comovement?

One of the pioneer papers in the RBC literature, Long and Plosser (1983), emphasizes the comovement of different sectors of the economy as an important feature of business cycles. These authors propose a multisector model that exhibits strong sectoral comovement. Long and Plosser obtain an elegant analytical solution to their model by assuming that the momentary utility is logarithmic and the rate of capital depreciation is 100 percent. However, many properties of the model do not generalize once we move away from the assumption of full depreciation.

Figures 3 and 4 show the strong comovement between employment in different industries as emphasized by Christiano and Fitzgerald (1998).[9] Figure 3 shows that, with the exception of mining, the correlation between hours worked in the major sectors of the U.S. economy (construction, durable goods producers, non-durable goods producers, and services) and aggregate private hours is at least 80 percent. The average correlation is 75 percent. Figure 4 shows that this comovement is also present when I consider a more disaggregated classification of industries. The average correlation of total hours worked in an industry and the total hours worked in the private sector is 68 percent. The correlation between industry hours and total hours workers were employed by the private sector is above roughly 50 except in mining, tobacco, and petroleum and coal. Hornstein (2000) shows that this sectoral comovement is present in other measures of economic activity, such as gross output, value added, and materials and energy use. These strong

[9] I constructed these figures using monthly data from January 1964 to April 2003. I detrended the data with the HP filter, using a value of λ of 14,400. I then used the detrended data to compute the correlations.

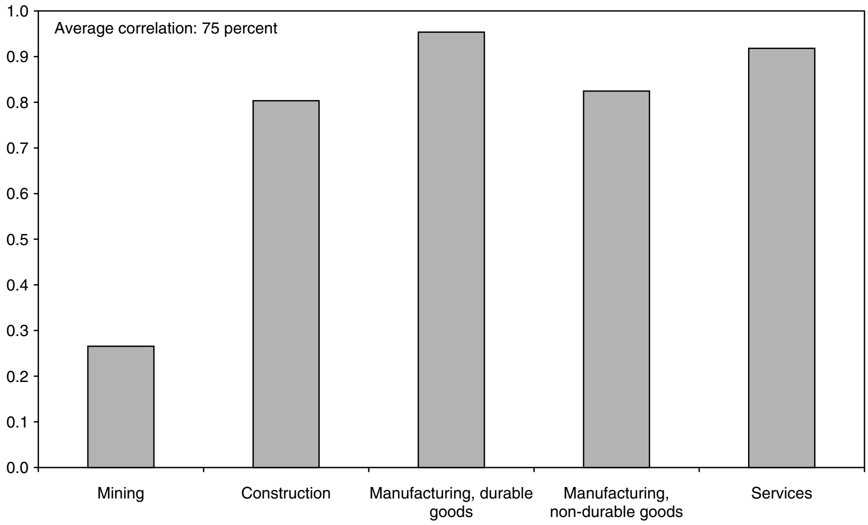

Fig. 3. Correlation between hours employed by industry and total hours employed by private sector (Monthly data, 1964-1 to 2003-4, HP filtered, $\lambda = 14{,}400$)

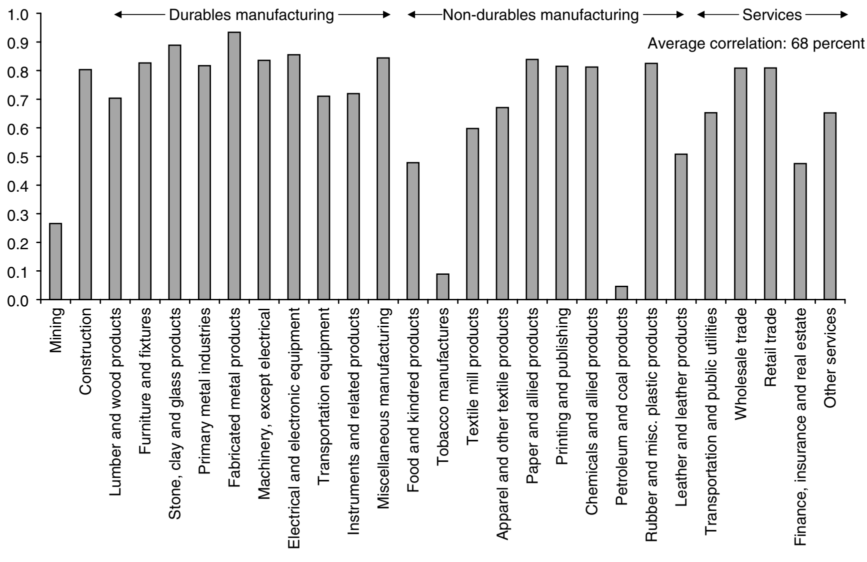

Fig. 4. Correlation between hours employed by industry and total hours employed by the private sector (Monthly data, 1964-1 to 2003-4, HP filtered, $\lambda = 14{,}400$)

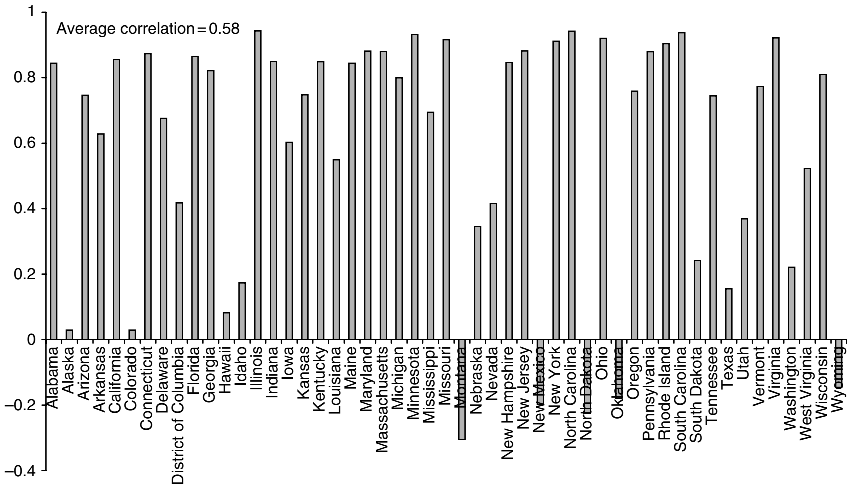

Fig. 5. Comovement across U.S. states. Correlation between real gross state product and aggregate U.S. real GDP (Annual data, 1977–1997, HP filtered, $\lambda = 100$)

patterns of sectoral comovement motivate Lucas (1977) to argue that business cycles are driven by aggregate shocks, not by sector-specific shocks.

Figures 5 and 6 show that, as discussed in Carlino and Sill (1998) and Kouparitsas (2001), there is substantial comovement across regions of the U.S. and across different countries.[10] The average correlation between real gross state product and aggregate real GDP for different U.S. states is 58 percent, with only a small number of states exhibiting a low or negative correlation with aggregate output. Figure 6 shows the correlation between detrended GDP in the U.S. and the remaining countries in the G7.[11] The average correlation is 46 percent. There is significant comovement across countries, but this comovement is less impressive than that across U.S. industries or U.S. states. Backus and Kehoe (1992), Baxter (1995), and Ambler, Cardia and Zimmermann (2004) discuss these patterns of international comovement.

At first sight, it may appear that comovement across different industries is easy to generate, if we are willing to assume there is a productivity shock

[10] I computed the correlations reported in Figure 5 using annual data from the Bureau of Economic Analysis on real gross state product (GSP) for the period 1977–1997. A discontinuity in the GSP definition prevents me from using the 1998–2003 observations. I detrended the data with the HP filter, using a λ of 100.

[11] I computed these correlations using annual data for the period 1960–2000 from the Heston, Summers and Aten (2002) dataset for the G7 (data for Germany is for the period 1970–1990). I detrended the data with the HP filter, using a λ of 100.

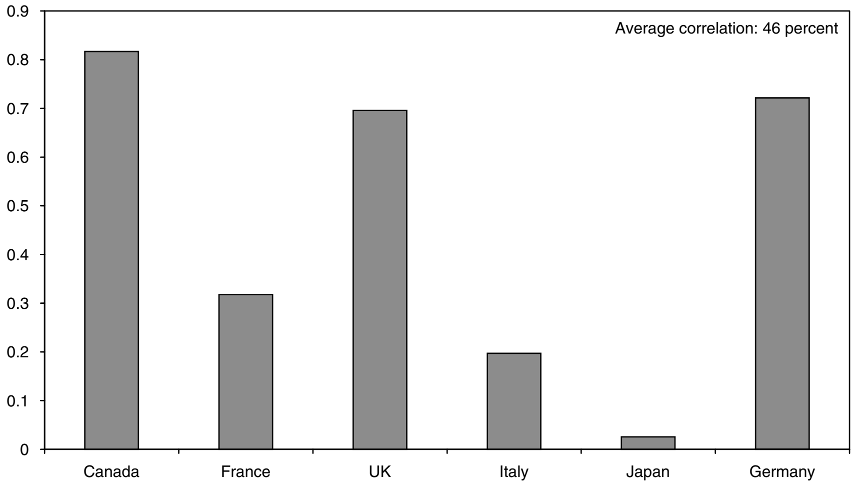

Fig. 6. Comovement of different countries with U.S. Correlation between country real GDP and U.S. real GDP (Annual data 1960–2000, HP filtered, $\lambda = 100$)

that is common to all sectors. However, Christiano and Fitzgerald (1998) show that even in the presence of a common shock, it is difficult to generate comovement across industries that produce consumption and investment goods. This difficulty results from the fact that when there is a technology shock, investment increases by much more than does consumption. In a standard two-sector model, this shock response implies that labor should move from the consumption sector to the investment sector. As a result, hours fall in the consumption goods sector in times of expansion. Greenwood *et al.* (2000) show that comovement between investment and consumption industries is also difficult to generate in models with investment-specific technical change.

One natural way of introducing comovement is to incorporate an input–output structure in the model; see, for example, Hornstein and Praschnik (1997), Horvath (2000) and Dupor (1999). However, because input–output matrices are relatively sparse, intersectoral linkages do not seem to be strong enough to constitute a major source of comovement.

Other potential sources of comovement that deserve further exploration are costs of moving production factors across sectors, as in Boldrin *et al.* (2001), and sticky wages, as in DiCecio (2003).

The comovement patterns illustrated in Figures 3 through 6 are likely to contain important clues about the shocks and mechanisms that generate business cycles. Exploring the comovement properties of business cycle models is an important, but under-researched, topic in macroeconomics.

IV. Conclusion

Methodological revolutions such as the one led by Kydland and Prescott (1982) are rare. They propose new methods, ask new questions and open the door to exciting research. I was very lucky to have been one of many young researchers who had a chance to participate in the Kydland–Prescott research program and get a closer look at the mechanics of business cycles.

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