Edmund Phelps: Macroeconomist and Social Scientist*

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Abstract

This paper recounts the major accomplishments of Edmund Phelps, winner of the 2006 Nobel Prize in Economics. (JEL code E0)

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I. Introduction

Edmund Phelps helped change the way we think about macroeconomic theory and policy, by introducing imperfect information and costly communication into the theory, and deriving their implications for the dynamics of inflation and unemployment. Phelps treated macroeconomics as a social science, whose subject matter is not just the choices people make but how people interact in groups. His pioneering efforts in developing a formal theory of the coordination mechanisms governing interactions led the way to a new kind of macroeconomics, one that was based on the interplay between the actions and expectations of individual actors, instead of being based on postulated relationships between macro aggregates.

Mainstream macroeconomics today projects a view of the economy that differs in important respects from Phelps's original vision. Whereas he portrayed economic interactions as being problematical and uncertain, leading to outcomes that intelligent people can adapt to but not anticipate, much of macroeconomics now is about the representative agent, content to interact with only himself and nature, or perhaps at arms length with "the market" through an unspecified agency that calculates equilibrium prices and executes preharmonized transactions. And people are typically portrayed now as understanding completely, up to stochastic error with known distribution, all economic forces. Indeed Phelps himself has changed his view on the significance of imperfect anticipation, having adopted a structural approach to unemployment that attaches only momentary importance to disappointed expectations as a driving force.

Even so, macroeconomics today has a connection with microeconomic reasoning that it never did before Phelps and a handful of others transformed the subject, and many of the concepts that Phelps himself introduced while making these contributions

in the 1960s and 1970s remain in use on the frontiers of the discipline, including the expectations-augmented Phillips Curve, the natural rate of unemployment, the island parable for understanding the real effects of demand shocks, efficiency wages, optimal inflation, staggered price-setting, and the customer-market model of price competition. These are important concepts. The expectations-augmented Phillips Curve is a central component of New Keynesian economics (Woodford, 2003), the matching function first introduced by Phelps in his analysis of search unemployment is the basic building block of the modern search/matching theory of the labor market, and Phelps's concept of optimal inflation is the intellectual foundation on which inflation-targeting central banks base their policies.

In addition to bringing microeconomic reasoning into the heart of short-run macro theory, Phelps introduced many of the basic concepts of modern growth theory. His work on the golden rule and dynamic inefficiency, the role of population growth in technological change, the factor-bias of technological change, the effects of risk on optimal saving, the implications of hyperbolic discounting and the role of human capital in the creation and diffusion of new technologies are still generating positive spillovers.

II. Macroeconomics before Phelps

To understand the nature of Phelps's contributions it is useful to recall the pre-existing state of mainstream macroeconomic theory in the mid 1960s. The prevailing orthodoxy was Keynesian IS-LM analysis with a fixed wage rate and/or fixed price level. Microeconomic foundations were being built for the various components of this analysis – the consumption, investment and money-demand functions – all of them being based upon rational choice theory taking expectations into account. But

these were foundations for understanding how people choose their demands, at given prices, on the assumption of what Clower (1994) has called "Hansen's Law" - that demand creates its own supply.[1] The behavioral functions were not integrated into any unified conceptual framework that could be used to study the effects of supply-side considerations or to model the evolution of wages and prices, other than the Walrasian model of instantaneous equilibration, a model that seemed to be contradicted by the evidence that wages and prices adjust slowly and that demand shocks cause output fluctuations.

By the mid 1960s, the Phillips Curve had become a standard approach to modeling wage adjustment. Phillips's (1958) original empirical finding had been interpreted theoretically by Lipsey (1960) as a disequilibrium adjustment function, according to which wages rose or fell as a function of excess demand or supply, which in turn was proxied by the unemployment rate. But it was still generally presumed that demanders would determine actual quantities, and disequilibrium adjustment was itself not explained in terms of any individuals' behavior, except insofar as reference was made to Walras's mythical "auctioneer".

Moreover, it was commonly accepted that the Phillips Curve represented a long-run tradeoff between inflation and unemployment, that it showed by how much inflation would have to rise if unemployment were to be reduced by any given amount and held there indefinitely. Although sophisticated analysts such as Samuelson and Solow (1960) accepted that the tradeoff would probably shift if a vigorous effort were made to peg the rate of unemployment at an unusually high or low number, as a result of changing expectations of inflation and skill-deterioration, among other factors, nevertheless there was not much that these analysts could do beyond pointing out that

[1] General equilibrium theorists working on adjustment problems (e.g. Hahn and Negishi, 1962) often assumed that the quantity transacted would be the minimum of demand and supply. This "short-side" rule entered mainstream macro briefly with the analysis of Barro and Grossman (1971).

some of the factors would work in one direction and some in another; there was no systematic framework for sorting out the long-run dynamic forces. So they typically regarded the Phillips Curve as presenting a meaningful tradeoff for long enough to be relevant for policy analysis, with no consideration of what would happen when enough time had passed for the effects of policy to cause the tradeoff to shift.

Phelps noted that this was not a satisfactory state of affairs. Macro theory was relatively uninformed by microeconomic reasoning. In the absence of any coherent story of how individual decisions are coordinated there was no good answer to questions such as why do variations in the quantity of money affect quantities of output and employment, rather than resulting in proportional increases in all wages and prices that would neutralize their effects on macroeconomic aggregates, why do firms when faced with a contraction of demand not simply underbid their competitors by a small amount and continue to sell the same quantities as before, how would the relationship between inflation and unemployment change over time as a result of policy interventions, and what would constitute an optimal inflation policy taking into account these induced shifts.

He was not alone in noting these problems. Kenneth Arrow (1967) had observed in his review of the first two volumes of Paul Samuelson's Collected Scientific Papers that the disconnect between micro and macro theory was a "major scandal." In (1959) he had made it clear that this was not just a problem with macro theory, that in fact the theory of general competitive equilibrium was seriously flawed because it provided no coherent account of who adjusts prices and why. Around the same time Hahn (1965) and Clower (1967) were noting that monetary theory was fundamentally inconsistent with established general equilibrium theory, and Clower (1965) was proposing a way to bridge the gap between Keynesian economics and general equilibrium theory. By 1968, when I was just starting my graduate work in economics, the

quest for a microfoundation to macroeconomics was underway, led by economists such as Clower, Leijonhufvud, Alchian, Mortensen, Hynes, Gordon, Lucas, and Rapping. Among the most prominent of these leaders was Ned Phelps.

Phelps and these other pioneers attributed much of the unsatisfactory state of economic theory to its inadequate treatment of information. The Walrasian paradigm that provided the only available coherent account of an economy's coordination mechanism supposed that accurate information about trading opportunities and about the behavior of one's trading partners was costlessly communicated at all times to all transactors, whereas many of the key elements of contemporary short-run macro theory, such as price stickiness and the real effects of demand shocks, seemed to depend on people making decisions while being less than fully informed about trading alternatives. What was needed was a new way of thinking about coordination that took these informational imperfections into account.

III. A new theory of labor market interactions

Phelps's most influential publication in this connection was his "Money-Wage Dynamics and Labor-Market Equilibrium" (1968), in which he undertook to provide a theoretical account of the Phillips Curve as reflecting rational behavior on the part of firms facing a random flow supply of potential new hires but imperfectly informed about the rate at which wages would be going up in the rest of the economy in the near future. In this analysis, a key assumption was that workers and firms are not continuously and costlessly in contact with one another as they would be in Walrasian general equilibrium theory; instead they meet randomly at a rate that depends positively on the number of searching unemployed workers and the number of vacancies, according to a function that we would now recognize as a matching function. The

matching function determines the economy-wide gross rate of hiring at any point of time.

The other key assumption was that, given the state of the labor market, an individual firm's quit rate will depend negatively on its wage relative to the average of other firms, and that its hiring rate will depend positively on the same relative wage. Accordingly the firm's net hiring will depend on its relative wage, as well as depending positively on the aggregate rate of unemployment and negatively on the aggregate vacancy rate. Phelps argued that, faced with this constraint, a firm wanting to fill a given number of vacancies will try to establish a relative wage that depends positively on its own vacancies as well as on the aggregate vacancy rate, and negatively on the current rate of unemployment. In attempting to achieve this desired relative wage it will set its nominal wage (assumed to be the same for new and old employees) equal to the desired relative wage times the expected average wage of other firms.

Under these assumptions Phelps showed that there will be a unique rate of unemployment such that if hiring is to take place at a rate that makes employment grow at the (given) rate of growth of the labor supply then the average firm's desired relative wage will equal unity. This is what we now call the "natural" rate of unemployment, although Phelps called it the "equilibrium" or "warranted" rate. At this rate the average firm will raise its wage offer at a rate equal to the expected rate of increase in the average wage rate.

A simplified version of this theory, cast in discrete time, goes as follows. There is a continuum of firms, with measure 1, and a constant population of workers. A matching function $h(u, v)$ indicates the flow of new workers that will show up at a firm with whom there will be a mutual gain in forming an employment relationship, when the unemployment rate is u and the vacancy rate is v. At the same time $q(u, v)$

workers will quit their current employment, so the change in unemployment is

$$\Delta u = z \left(\underset{(-)}{u}, \underset{(-)}{v} \right) \tag{1}$$

where $z = q - h$ is minus the net flow of new hires.

Meanwhile, the average firm will attempt to set its relative wage (one period in advance) as a decreasing function of the rate of unemployment and an increasing function of the number of vacancies it is trying to fill:

$$w_+ = w^e \cdot m \left(\underset{(-)}{u}, \underset{(+)}{v} \right), \tag{2}$$

on the grounds that a higher relative wage will help boost recruiting and deter quitting, but is needed less when the workers' alternatives are diminished by higher unemployment or fewer vacancies elsewhere. The average wage next period w_+ will be proportional to the expected wage w^e because the firm understands that in order to control turnover it needs to control its relative wage.

This paper made several major contributions to the literature. To begin with, for the first time in mainstream macroeconomic theory, it used detailed microeconomic reasoning to study how market interactions take place and how wages and prices are determined. In Phelps's analysis, wages were set by the same economic agents that were choosing demands and supplies, instead of by the auctioneer. And neither demand nor supply determined the quantity of labor traded; instead the market would typically be characterized by the simultaneous existence of vacant jobs and unemployed workers, thanks to the frictions encapsulated in the matching function.

The paper's second contribution was to introduce the concept of the natural rate of unemployment, analyze its determinants, and show that in the long run the only

possible equilibrium rate of unemployment is the natural rate, independently of the rate of inflation. In my simplified discrete-time formulation the natural rate is the rate at which actual and expected wage increases are equal, given a vacancy rate that makes unemployment constant.

More precisely, according to (1) unemployment will converge to a constant rate u only if the vacancy rate approaches the solution $\widetilde{v}(u)$ to

$$z(u, v) = 0$$

where $\widetilde{v}$ is decreasing in u. So constancy of unemployment implies the relative wage equation:

$$w_+/w^e = m(u, \widetilde{v}(u)) \tag{3}$$

and equality between actual and expected average wage rates with constant unemployment requires u to equal the natural rate u^n defined by

$$m(u^n, \widetilde{v}(u^n)) = 1, \tag{4}$$

which is unique because the left hand side is strictly decreasing in u^n.

Before Phelps's paper there had been some discussion of the impossibility of using inflation to make unemployment deviate indefinitely from an invariant long-run equilibrium rate (for example, Lerner, 1949 and Friedman, 1966), but this discussion had been more a matter of general principle (the absence of money illusion and the presumed neutrality or super-neutrality of money) than of formal analysis and coherent conceptual foundations.[2] Friedman (1968) is often cited in connection with the

[2]There was a large theoretical literature at the time on the superneutrality of money, but it mainly dealt with long-run issues of capital accumulation and abstracted from unemployment.

natural rate hypothesis, but in fact Phelps deserves at least as much credit, and I would argue even more, although it was Friedman who coined the term "natural rate of unemployment", deliberately paraphrasing Wicksell's "natural rate of interest." Phelps's analysis was more precise, deeper and more operational than Friedman's. Instead of writing out a formal model of the determination of the natural rate, Friedman was content to say that it was the rate "that would be ground out by the Walrasian system" if appropriate account were taken of imperfections, costs of information, structural characteristics of the labor market, etc. Phelps actually provided such an account, and it involved going far beyond the Walrasian system.

Since 1968 many macroeconomists have concluded that short- and medium-run movements in unemployment are often movements in the natural rate itself, rather than fluctuations around the natural rate. This idea has motivated a great deal of theorizing about how the natural rate reacts to demographic changes, changes in labor-market regulation, oil prices, etc. Phelps himself (1994) has developed a systematic theory of how changes these variables and in global capital markets can generate long swings in the natural rate. The starting point for all these developments is his 1968 paper. Going beyond this has required a deeper analysis of the m and z functions and of the vacancy rate. But the basic conceptual framework was built to last, and has needed surprisingly little modification.

A third contribution, closely related to the second, is that the paper produced the first analytical demonstration of the "accelerationist" proposition to the effect that any attempt to maintain a rate of unemployment below the natural rate would lead to hyperinflation. Logically this proposition is a direct consequence of the natural rate hypothesis and adaptive expectations. That is, according to (3) an unemployment rate that converged to any value $u < u^n$ would result in average wages always being more than expected, implying that, if current wages are always known, wage inflation

would always be more than expected. With adaptive expectations this implies that expected wage inflation would always be rising but would never catch up to actual inflation. Although the step from the natural rate to the accelerationist proposition is a small one theoretically, it is of such importance for policy purposes that a clear analytical demonstration in the context of a micro-based analysis of market mechanisms was an important contribution.

A fourth contribution of the paper was to provide what seems to be the first example of a formal model of efficiency wages. That is, one of the reasons why a firm will not always cut wages in the face of unemployment is that wage cuts might induce quitting and thereby increase the firm's turnover costs. This is one of the factors that motivated Phelps's relative wage function m. It is not clear from reading the paper that Phelps realized the importance of this contribution at the time, as the wage function was motivated as much by the fact that there was not an infinitely elastic instantaneous supply of new recruits as by the desire to limit quitting. But either story is enough to generate the main result of efficiency wage theory, namely that a firm will may want to raise its relative wage even when there are unemployed workers knocking on its door. And in either case unemployment is involuntary, in the sense that the unemployed envy the employed.

A fifth contribution, which seems to have gone largely unmentioned in the literature, is that the paper provided the first formal analysis I can find of a dynamic economic model in which the endogenous state variables include trading relationships, as well as the more conventional prices, quantities and expectations. In this case the relationships involved are employment relationships. Forming trading relationships is costly and time consuming, and the economy's near and medium term outlook depends partially on how many trading relationships of various kinds exist now. This theme has been taken up in the modern search/matching theory of unemployment

developed by Mortensen and Pissarides,[3] whose basic building block is the matching function first introduced in the 1968 Phelps paper. A key assumption in this theory is that forming a trading relationship involves a significant setup cost, which results in a quasi-permanent attachment unlike the one-night stands that are modeled in search theories of money following Kiyotaki and Wright (1989). This final contribution remains relatively undeveloped in modern macroeconomics, although search and matching is still an active area of research (see for example Rogerson, Shimer and Wright, 2005).

Interestingly, one thing that this 1968 paper did not do is demonstrate what most people think of as the key implication of the natural rate hypothesis, namely the proposition that the economy if left alone will ultimately gravitate to the natural rate of unemployment. This proposition is implicit in Phelps's analysis of the natural rate, but it cannot be deduced from his assumptions, because that would require endogenizing the vacancy rate, which in turn would require integrating this labor market analysis with an analysis of adjustment in the rest of the economy, including capital markets and goods markets.

How to conduct this integrated analysis of multi-market adjustment was the focus of an active literature at the time. The earlier analysis of Clower (1965) and Patinkin (1965), which led to the general disequilibrium analysis of Barro and Grossman (1971), Benassy (1975) and others had made it clear that interrelationships between adjustment in multiple markets could make convergence to general equilibrium problematical. Unemployment can depress aggregate demand through non-price interactions (quantity rationing in the labor market) that feed back to further reductions in the demand for labor (vacancies) causing unemployment to fall even further. Such positive feedback loops add to the destabilizing effects of inflation expectations

[3] See Pissarides (2000).

and debt deflation that Keynes had emphasized. Leijonhufvud's (1968) masterful reinterpretation of Keynes's *General Theory* seemed to many of us at the time to show the way to an understanding of the self-adjusting properties of a free-market economy by integrating general disequilibrium analysis with the informational economics of Phelps and others. But this turned out to be an extremely hard problem, one on which we are still trying to make progress. Under what circumstances, through what mechanisms and how quickly unemployment will return to its natural rate when displaced by a shock is something we do not understand very well.

The fact that Phelps could accomplish so much without addressing what might seem the most important issue involved illustrates the role of opportunism in promoting scientific progress. If at first you don't succeed, redefine the question. Phelps cut through the difficulties of multi-market adjustment by answering a slightly different pair of questions, namely what the rate of unemployment would be *if* the economy converged to a long-run equilibrium, and what would happen if economic policy succeeded for some time in keeping the actual unemployment rate below the natural rate.

IV. Optimal inflation policy

In "Phillips Curves, Inflation Expectations, and Optimal Employment over Time" (1967), Phelps undertook to provide an account of optimal inflation policy in an economy characterized by, among other things, an expectations-augmented Phillips Curve. In effect, this paper took as given the inflation-unemployment mechanism to which Phelps (1968) later provided a micro foundation.

This paper was the first to introduce the notion of "the expected rate of inflation" into formal analysis of the Phillips Curve, although the notion goes back at least to

Fisher (1896)[4] and had already been used in other parts of formal monetary theory by Cagan (1956), Bailey (1956) and Phelps (1965a). More specifically, this paper was the first to introduce the concept of an "expectations-augmented Phillips Curve", of the form

$$\pi = f\left(u - u^n\right) + \pi^e \tag{5}$$

in which the rate of inflation π depends on the rate of unemployment u and the expected rate of inflation π^e, f is a decreasing function with $f\left(0\right) = 0$, and there is a unit coefficient on expected inflation.[5] This analytical construct has remained part of the core of macroeconomic theory every since.

The paper derived an intertemporal social welfare function $W\left(u, \pi^e\right)$ that depends upon the employment rate and the expected rate of inflation, from explicit micro foundations. And it was the first attempt to study the optimal time paths for inflation and unemployment using the analytical techniques that were being developed at the time in the optimal growth literature.

Specifically, in continuous time, with inflation expectations being formed adaptively:

$$\dot{\pi}^e = \alpha\left(\pi - \pi^e\right)$$

with a speed of adaptation α, the problem of maximizing $\int_0^\infty e^{-\rho t} W dt$ is an optimal control problem with one state variable π^e and one control variable u. This formulation made it clear that the tradeoff between inflation and unemployment is a dynamic one. Instead of choosing simply between less unemployment and less inflation, the policy maker has to choose between less current unemployment and less

[4] Dimand (1999) notes that the relationship between expected inflation and interest rates, often attributable to Fisher, actually goes back as far as Douglass (1740), although Fisher's analysis was the first mathematical one and the first to involve statistical estimation.

[5] Taking logs on both sides of the relative wage equation (3) derived in the 1968 paper shows that it is identical to (5), with $f\left(u - u^n\right) = \ln m\left(u, \widetilde{v}\left(u\right)\right)$ and $\pi = \ln w_+ - \ln w$.

future inflation.

In this formulation, more unemployment is an investment in lower inflation expectations. In the long run the optimal rate of inflation (both actual and expected) will converge to a value π^* determined by the steady-state Euler equation:

$$\frac{W_\pi\left(u^n, \pi^*\right)}{W_u\left(u^n, \pi^*\right)} = \rho \frac{1}{-\alpha f'(0)} \tag{6}$$

which says that, measured in terms of unemployment, the marginal return from lower expected inflation, given by the marginal rate of substitution on the left-hand side, should yield the social rate of return ρ on the marginal cost.

One of the major turning points in the development of modern macroeconomics occurred in the 1970s when people began to see instability in the Phillips Curve at a time when expectations of inflation were beginning to rise. The discussion on page 256 of Phelps (1967) predicted this instability well in advance, by noting that the conventional unaugmented Phillips Curve may fit the data well during a period in which inflation has been under control, but that if inflation subsequently drifts above its historical range this will result in a rise in expected inflation, causing new data points to lie systematically above the previously fitted curve.

Following the contributions of Lucas (1972) and others, the profession quickly replaced Phelps's assumption of adaptive expectations by the assumption of rational expectations. But the expectations-augmented Phillips curve and the natural rate hypothesis were readily adaptable to the new expectational assumption. Indeed, Sargent (1971) used the natural rate hypothesis in one of the first demonstrations of the econometric implications of rational expectations, showing that, in a regression of inflation on unemployment and a distributed lag of past inflation, the hypothesis implies that the coefficients on the past inflation terms should take on whatever values

best predict future inflation, rather than automatically summing to unity as implied by adaptive expectations.[6] The expectations-augmented Phillips curve was also used under rational expectations as the centerpiece of the theory of time-consistency in monetary policy, for which, along with real business cycle theory, Kydland and Prescott received their Nobel Prize in 2004.

Moreover, much of the theoretical underpinning for the policy of inflation-targeting, which many central banks have adopted since 1990, including New Zealand, Canada, the UK, Israel and Sweden, also derives directly from the framework developed in this paper of Phelps. The most advanced development of that underpinning is provided by Woodford (2003), whose analysis of optimal inflation policy can be seen as an improved and deeper version of Phelps's analysis.

With the newly emergent literature on macroeconomic learning (Sargent, 1999; Evans and Honkapohja, 2001; and especially Orphanides and Williams 2005) adaptive expectations is making a comeback in the journal literature, although in somewhat modified form; this development is making the modern analysis of optimal inflation targeting look even closer to Phelps's than it was a decade ago. And the analysis of Fuhrer (1997) and others has opened a vigorous debate over whether a forward-looking Phillips curve with rationally expected inflation on the right-hand side or a backward-looking curve with lagged inflation, as in Phelps's adaptive-expectations approach, best fits the data.[7]

[6] Sargent (1971) presented this analysis as a rebuttal to Solow (1968), who rejected the natural rate hypothesis on the grounds that the coefficients on lagged inflation summed to less than unity. But, as Laidler (1970) pointed out, this result of Solow's appears to be an artifact of his having included not only lagged price inflation but also money wage inflation on the right-hand side of his equation. Laidler's (1973) subsequent estimation, which omitted wage inflation, found a coefficient on lagged price inflation that was almost exactly equal to unity.

[7] Credit for the adaptive expectations formula with which both Phelps and Friedman augmented the Phillips Curve actually belongs to Phillips himself. According to Cagan (2000), Phillips suggested the idea in 1951 to Milton Friedman, who passed it along to Cagan, who was the first to employ it in the literature.

V. Other work on unemployment and inflation

Phelps made many other contributions that deepened our understanding of the nature and macroeconomic significance of imperfect information. One such contribution is Phelps and Winter (1970), which analyzed the formation of prices, as opposed to wages, under imperfect information and costly search on the part of customers. Phelps and Winter recognized that slow diffusion of price information provides even an atomistic firm with temporary monopoly power, and hence produces a dynamic tradeoff between more profit today and more customers (and hence more profit) in the future. This paper provided one of the first systematic explanations of why prices do not always mirror marginal costs, even in a world of "atomistic" competition. It also generated a large literature on "customer markets" that included such important contributions as Okun (1981). In this paper too the endogenous state variables included trading (customer) relationships.

Although Phelps (1969) does not produce a formal model, it is arguably one of his most significant contributions to the development of the micro foundations of macro theory. For it is in this essay that Phelps outlined the famous "island" parable that illustrates how imperfect information can give rise to price stickiness and to real effects of monetary policy even in a world where there are no physical or regulatory impediments to price adjustment, where no one is behaving irrationally and where all perceived gains from trade are fully exploited. The basic idea is that producers respond to nominal shocks because under restricted information about other prices they believe with some probability that changes in their nominal selling prices produced by such shocks are changes in their relative selling prices. This very parable was the explicit conceptual foundation of Lucas's (1972) paper on "Expectations and the Neutrality of Money," one of the most influential contributions to 20th Century

economics.

Phelps (1972) further analyzed the notion of the natural unemployment rate and introduced the notion of "hysteresis" which has played a major role in the literature on inflation-unemployment dynamics. Once again, as in the Phelps-Winter paper, the fact that trading relationships, whether customer or employment relationships, are slow-moving state variables is key to understanding the evolution of macroeconomic outcomes. The experience of being without an employment relationship causes a worker's skills to deteriorate and more generally diminishes the worker's chances of regaining employment.

Modern New Keynesian macroeconomics derives its expectations-augmented Phillips Curve not from the search-theoretic foundations of Phelps's earlier contributions but instead from an analysis in which there are nominal wage and/or price contracts that impede price flexibility. But here again Phelps was a leader. Specifically, Phelps and Taylor (1977) showed how in such a model, even if everyone has rational expectations, nevertheless systematic monetary policy can have important real consequences. In the formulation of this paper systematic policy cannot affect the long-run average size of the real output gap, but it can determine the variance of that gap, along with the variance of inflation. In modern discussions of monetary rules under rational expectations this idea of a tradeoff between the variances of different policy objectives is of primary importance, and this 1977 paper seems to be the first place in which such a tradeoff was derived under rational expectations. (Interestingly, in his what was probably his last contribution to monetary economics, Milton Friedman (2006) put forth the argument that this variance tradeoff is no more stable empirically than the original pre-Phelps/Friedman unaugmented Phillips curve.)

This early work on price contracts was later refined by Taylor in his work on monetary policy, and by Calvo (1983) who developed it into a framework that is

now one of the linchpins of New Keynesian analysis. Another development by Phelps (1978) shed light on one of the most difficult policy problems of the last third of the 20th Century, by analyzing the dynamics of disinflation under staggered wage contracts. Specifically, this paper showed that under rational expectations there is a way to disinflate at no cost in unemployment, despite the stickiness of wages.

Phelps (1983) made yet another path-breaking contribution to our understanding of how imperfect information can interfere with the smooth coordination of economic activities and can thereby give real effects to monetary policy in a world where markets clear and no one suffers from any illusions or irrationality. In this paper he recognized that to invoke rational expectations is to go beyond any assumptions about peoples' cognitive ability, because the assumption applies not just to each agent individually but to the economic system as a whole. In effect, in order for each actor in the economy to have rational expectations, the actor's beliefs must somehow be coordinated with the beliefs of all other actors. Thus to assume rational expectations is to implicitly invoke some unspecified coordination mechanism, much the way that the assumption of general equilibrium invokes something like the Walrasian auctioneer.

Phelps makes this point by noting that someone possessing a correct model of the economy, according to which actual inflation depends on the average forecast of all people, may try to forecast inflation by forecasting the average forecast of inflation and then fitting this forecast of forecasts into the correct model. But by the same token this person should realize that others are doing the same, and should therefore try to forecast the average forecast of the average forecast of inflation, and so on with infinite regress. As Phelps points out there is no general reason why this regression should converge to rational expectations. The development of this line of analysis, which has been applied to many areas of macroeconomics, originates with this paper of Phelps and the related work of Frydman (1982).

More recently, Phelps (1994) developed his theory of the natural rate into a theory of structural unemployment, by integrating it with an analysis of equilibrium in goods and capital markets. The work represents a significant movement away from his analysis of short-term adjustment, and an even heavier reliance on the assumption of gravitation towards the natural rate. In attempting to explain the dramatic and persistent rise in European unemployment over the 1970s and 1980s, he concluded that the best way to understand this movement is not as a failure to converge to the natural rate but as a long upward movement of the natural rate itself. But even though the role of disequilibrium is played down, imperfect information and problematical social interactions remain at the core of the analysis, which is based on efficiency wages to discourage quitting and shirking, and on firms' decisions to invest in building trading relationships with employees and customers. The analysis has succeeded in convincing even many of the Keynesian economists who at first resisted the idea that aggregate demand was not the main culprit.[8]

VI. Contributions to Growth Theory

In addition to his contributions to the micro-foundations of employment and inflation theory, Phelps has made valuable original contributions to the theory of economic growth. In (1961), in one of the most remarkable cases of multiple discovery in the history of economics, along with Allais, Beckmann, Desrousseaux, Robinson, Swan and von Weizsäcker he discovered and demonstrated that, under quite general circumstances, the balanced growth path with the highest possible level of consumption must obey what he called the "golden rule of accumulation," which requires that the country's saving rate equal the fraction of national income accruing to owners

[8] See for example the testimony of Olivier Blanchard (2003).

of capital. This same paper showed that under ideal conditions the golden rule is mathematically equivalent to the condition that the rate of return to investing in capital be equal to the rate of economic growth. In (1965b) he clarified this result by demonstrating that in an economy where so much capital has been accumulated that the profit rate has fallen below the rate of economic growth, a Pareto improvement can be engineered by having everyone consume more; the benefit of not having to devote so much income to maintaining the capital stock per efficiency unit of labor in the face of increasing numbers of efficiency units would outweigh the lost marginal product. The golden rule of accumulation remains the most basic proposition of optimal growth theory.

After having shown how violation of the golden rule would lead to oversaving, Phelps collaborated with Pollack (1968) to show how hyperbolic discounting could lead to undersaving. This artful specialization of Strotz's (1956) time-inconsistency analysis showed us how to think about economic growth when saving is controlled by rational policy makers unable to commit their successors, arguably a more realistic scenario than the perfect commitment implicit in Ramsey. In the hands of David Laibson, Phelps's analysis has become the cornerstone of a major branch of behavioral economics.

Another of Phelps's early pieces on optimal growth theory was his (1962) paper on optimal saving under uncertainty, in which he showed that, with the isoelastic preferences that are now commonly used in growth theory, uncertainty about the rate of return to capital depresses saving if and only if an increased expected return stimulates it, which is also if and only if the coefficient of relative risk aversion is less than unity. Samuelson's (1969) later integration of saving and portfolio choice was built on the foundation of this analysis, which remains part of the modern macroeconomist's toolkit.

Three other contributions of Phelps, which lay dormant for many years waiting for the profession to catch up, helped lay the foundations for the modern theory of innovation-based growth. The first was his (1966) paper on the golden rule of research, which clarifies the relationship between population and technological change, under the assumption that labor-augmenting productivity A evolves as

$$\dot{A} = H(A, R)$$

where R is the number of researchers and H is continuous. He makes several points that have played an important role in modern discussions. First, making A endogenous implies a departure from the conventional assumptions of perfect competition and no externalities, because there are now increasing returns in all factors including A, which means that no equilibrium exists under the conventional assumptions. Second, under what he described as reasonable assumptions on the H function, namely constant returns in A and R, if R grows asymptotically at the rate of population growth n then the long-run rate of productivity growth will also be equal to n. Third, the reason for this remarkable result is that as the stock of undiscovered ideas becomes depleted, more researchers are needed in order to sustain a constant rate of discovery.

The first of these ideas is fundamental to all innovation-based growth models, and was emphasized by Romer (1986) at the start of the modern endogenous-growth revolution. The second idea is almost exactly the conclusion of Jones's (1995) semi-endogenous theory, which relaxes the linear homogeneity of H and concludes that productivity growth will be asymptotically proportional to population growth, provided that H is strictly concave in A. The third idea is exactly the rationale given by modern semi-endogenous theory. Even if the evidence in favor of semi-endogenous

theory is not entirely compelling (see Ha and Howitt, 2007) Phelps's forty-year-old account is still instructive to the modern student.

A second contribution of Phelps to modern growth theory is his 1966 paper with Drandakis on the direction of technological change, which presents another example of the importance of opportunism in economic science. Lacking any clear rationale, Phelps adopted the artful simplification of supposing that a given stock of R&D resources would be allocated in such a way as to maximize the current growth rate of total factor productivity. Although Kennedy (1964) had earlier made the same assumption, Phelps went much further, showing that convergence to a situation with constant factor shares and a constant productivity growth rate requires the elasticity of substitution between labor and capital in the aggregate production function to be less than unity, and in the case where the economy's saving rate is constant this in turn implies that technological progress will be purely labor-saving (Harrod-neutral) in the long run.

Why technological progress should exhibit the Harrod-neutrality necessary for a balanced growth path with constant factor shares to exist is one of the key issues of modern growth theory. Jones (2005) argues that in the long run all production functions are Cobb-Douglas, which implies Harrod-neutrality of all technological progress. Aside from this the only available explanation is that of Acemoglu (2003), whose analysis amounts to almost the same thing as that of Drandakis and Phelps. Although Acemoglu bases his analysis on a modern account of the R&D decision, which was not available to Drandakis and Phelps, it arrives at the same conclusion as Drandakis and Phelps, and for essentially the same reason.

Whether this collection of papers will end up being seen as proof that the economy's elasticity of substitution must be less than unity (or equal, in the Cobb-Douglas case) depends on whether the idea of constant factor shares continues in the future

to be regarded as a stylized fact of long run growth. Recent research by Caselli and Feyrer (2006) and others seems to indicate that the share of capital, broadly interpreted to include human as well as physical capital, increases with economic development, contrary to the constancy that earlier writers had taken as given. Moreover, a recent quartet of working papers[9] provide theoretical grounds for believing that in the long run the share of capital will approach unity.

In 1966, together with Richard Nelson, Phelps developed a theory of the role of human capital in the growth process, which postulates that education is important as a factor to facilitate, generate, and adapt to technological change, rather than as a factor of production like labor or land or machinery under a given state of technological knowledge. This theory has been used by Benhabib and Spiegel (2005) to help explain why differences in the level of human capital across European countries seem to have such small effect on levels of income per person. It has also been used by Galor and Tsiddon (1997) and by Aghion, Howitt and Violante (2003) to help explain the rise in wage inequality in many countries during the last third of the 20th Century, the idea being that acceleration of technological progress raised the premium on education as a factor involved in adapting to change.

More generally, the simple framework of Nelson and Phelps, in which productivity grows as

$$\dot{A} = \phi \cdot \left(\overline{A} - A\right)$$

with the coefficient ϕ representing a country's "absorptive capacity" and $\overline{A}$ a "frontier technology," has been integrated into modern innovation-based growth theory as applied to countries in which technology advances more through implementation of foreign inventions than through frontier innovation. In these theories, the coefficient

[9] Givon (2006), Peretto and Seater (2006), Zeira (2006) and Zuleta (2006).

ϕ represents the frequency of implementations in the average industry. Aghion and Howitt (2006) have turned these ideas into a theory of "appropriate growth policy", by recognizing that growth is promoted by different policies in countries far from the technology frontier, where technology improves mainly through implementation, than in countries close to the frontier that rely more on frontier innovation, because policies that are most effective at promoting innovation are typically not the same as those that are most effective at promoting implementation. Although this modern theory endogenizes ϕ more explicitly than Nelson and Phelps were able to, it follows Nelson and Phelps in making education one of the key determinants.

VII. The nature of Phelps's contribution

The most visible feature of Phelps's contributions to macroeconomics is the sheer number of his creations that are continuing to have a major impact on the profession decades later. I have spent most of this paper describing the ideas related to inflation and unemployment, because this is what the Nobel Committee focused on, rightly so I think, when awarding his Prize. But the contributions go on into growth theory, social choice, public finance, entrepreneurship, the economics of transition, and on and on.

Beyond the sheer number is the depth of those ideas. One measure is the number of Nobel Prizes that have been awarded for work that builds essentially on Phelps's contributions. As mentioned above, the basic conceptual framework of Lucas (1972) was Phelps's "island parable." Kydland and Prescott (1977) analyzed monetary policy using the formal framework first spelled out by Phelps (1967), and even their analysis of time-consistency was to some extent foreshadowed by Phelps and Pollak (1968). One of the concepts for which Friedman is best known is the natural rate

of unemployment, a concept whose development and formal analysis actually owes more to Phelps than to Friedman. Indeed, Phelps even played a big role in laying the foundations of the real business cycle analysis for which Kydland and Prescott were cited, in the sense that Phelps led the path towards a theory of short-run macroeconomics based on the twin neoclassical principles of equilibrium and rationality (although Kydland and Prescott did not deal with the informational imperfections that Phelps had stressed).

By 21st Century standards, Phelps's work on inflation and unemployment might seem somewhat incomplete. In his 1968 paper, for example, the vacancy rate and the critical z and m functions were taken as given rather than being derived from an explicit analysis of profit and utility maximization. To some extent this characteristic reflects Phelps's opportunism again. He was wrestling with problems of disequilibrium adjustment that much of the modern literature has ignored. If he had stopped to dot all the i's who knows how much longer we would have had to wait? In any event one can reasonably ask whether explicit maximization is a useful concept for understanding the adaptive processes he was trying to model. Most importantly, if today's theory looks more deeply rooted in microeconomic principles than Phelps's 1968 analysis this is largely because today's writers are standing on his shoulders.

Another important aspect of Phelps's contribution to economics is that so much of it took place outside of his own writings. He fostered path-breaking research into imperfect information in macroeconomics by gathering researchers together, encouraging them and publicizing their findings. The prime example of this is the Phelps et. al (1970) volume, which for a generation of macroeconomists stood as the manifesto of a new information-based macroeconomic theory. Phelps was the prime mover in organizing and publishing these contributions, his introduction to the volume was an inspiration to many researchers, and many of the contributions contained in the

volume were elaborations of his own earlier work, especially Phelps (1968), which was also reprinted in modified form in the volume. Another example of this kind of contribution was the conference organized by Frydman and Phelps to investigate the problem of coordinating expectations, which resulted in the publication of Frydman and Phelps (1983).

To my mind the most salient aspect of Phelps's contributions is how seriously he has taken macroeconomics as a social science - not a study of bloodless efficiency but of social interactions. He tackles important social issues - unemployment, inflation, technological change, fiscal policy, social justice. And he stays with them until he has discovered something fundamental about how society works. This is why his ideas stay with us in the long run.

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