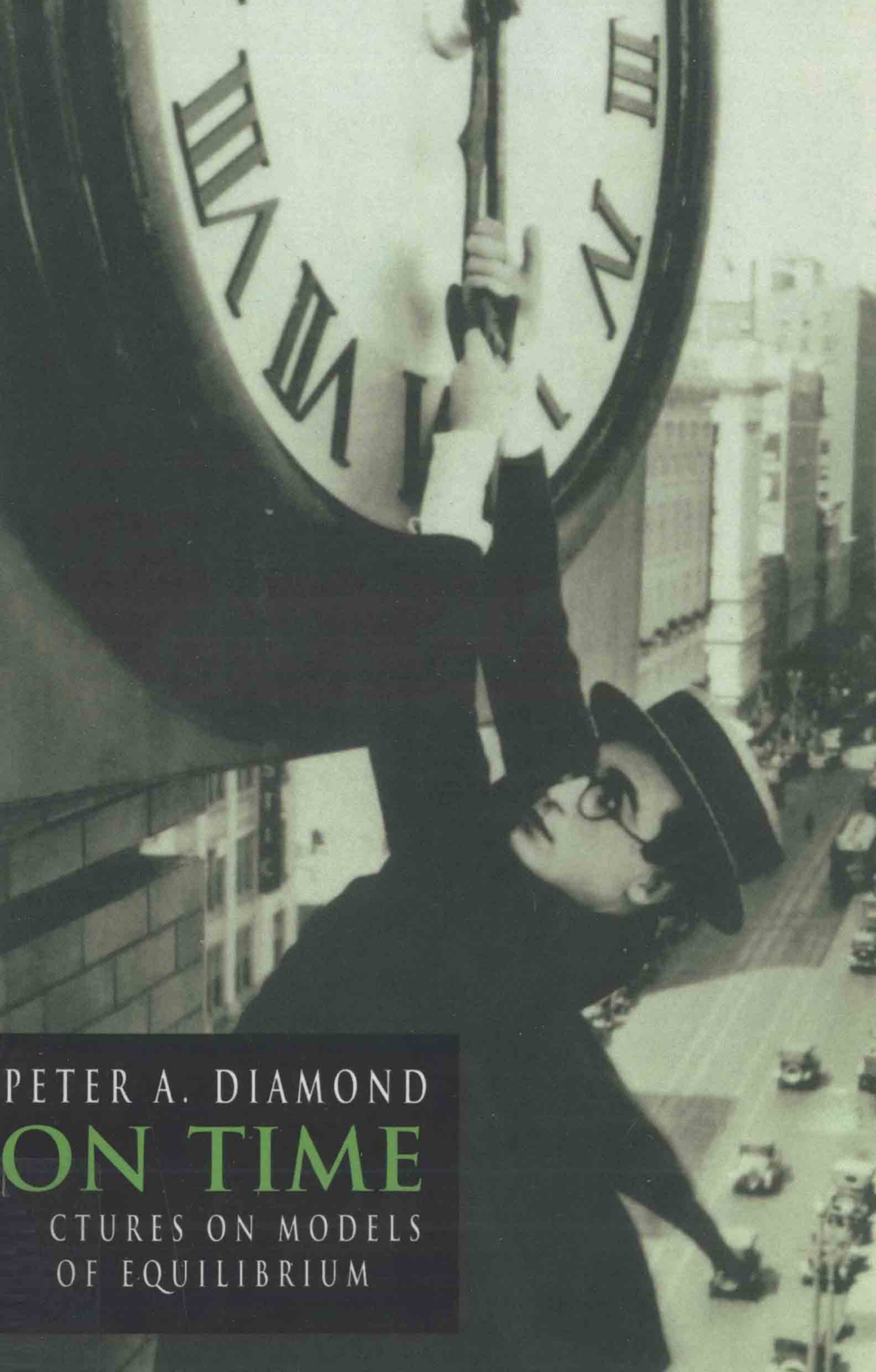

PETER A. DIAMOND

ON TIME

CTURES ON MODELS
OF EQUILIBRIUM

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PREFACE

I have been researching the inadequacies of conventional approaches to the modeling of time since 1968. My dissatisfaction with treatments of tâtonnement stability led me to think about price adjustments in real time, with individuals aware that they are partaking in a process in real time. This approach to modeling equilibrium resulted first in my 1971 analysis of search equilibrium in a single market. Reading Mortensen (1978) made me realize the power of Poisson processes for developing tractable models of real time activities and moved my concern for real time allocation processes into a more productive phase. These lectures represent an attempt to express the image of the workings of an economy that lies behind much of my research. Being invited to give these lectures pushed me into a reflection on modeling that would not have occurred otherwise.

The book is divided into two lectures; each lecture is divided into two chapters. In the lecture about individual industries, I begin by considering explicit modeling of time in a competitive setting where investment and production are the only decisions by firms; the Walrasian auctioneer handles prices. The thrust of the lecture is how atemporal modeling is (and must be) informed by explicit-time thinking and modeling. This is illustrated by a model with uncertainty about the production costs of individual firms and is argued by consideration of data on gross and net employment flows. The second chapter moves beyond this structure by recognizing price setting as a control variable of individual suppliers, dropping the fiction of the Walrasian auctioneer. Consideration of price setting leads one to models of monopolistic competition and of limited

information about prices and trading opportunities. Reviewing the behavior of prices over time illuminates the kind of model we need.

The second lecture considers how a model of an entire economy needs to be more than a model of a single industry. Again, there are two chapters. The first considers general modeling questions and evidence on the behavior of entire economies over time. The second considers atemporal and explicit-time models of an entire economy, with a focus on the acquisition of purchasing power.

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This book is an expanded version of two lectures presented on May 4 and 5, 1993 at Cambridge and interestingly discussed by Jim Mirrlees on May 6. I am grateful for having had the opportunity to give the lectures, and for the pleasure of spending time at Churchill College again. Cambridge in May can be wonderful, and was. Frank Hahn was the perfect host.

These lectures reflect a large debt to my continuing collaborator, Olivier Blanchard. His valiant efforts to teach me macroeconomics have had mixed success, as shown in these lectures. I have also received valuable comments on earlier drafts from Daron Acemoglu, Abhijit Banerjee, Roland Bénabou, Ricardo Caballero, Stan Fischer, Harry Gakidis, Frank Hahn, Matthew Rabin, Bernie Saffran, Lones Smith, Bob Solow, Nick Stern, and Peter Temin. Helen Dippold has handled details of the manuscript with initiative, accuracy, and cheerfulness.

I also want to thank the National Science Foundation, not only for support while writing this book, but also for support when I researched the various topics that this book attempts to address.

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LECTURE 1

MODELING AN INDUSTRY

CHAPTER 1

SHORT RUN AND LONG RUN

In the Preface to the first edition of his *Principles of Economics*, Alfred Marshall refers to the "element of Time" as "the centre of the chief difficulty of almost every economic problem" (1948, p. ii). I share Marshall's view of time as a source of difficulty. The picture of Harold Lloyd conveys my image of a theorist grappling with the modeling of time. In these lectures, I will examine how time is modeled in various economic analyses. My focus will be on the modeling of equilibrium, particularly equilibrium with many economic agents.[1] I will present a leisurely tour through some economic analyses, with an eye on their treatment of time. The first lecture considers models of a single industry; the second, models of an entire economy. My hope is that economic analyses will improve from awareness of the link between how time is modeled and some of the conclusions reached by the models.

1.1 Short run and long run

In Book V of his *Principles*, Marshall considers equilibrium. Let me quote a summary paragraph:

> [M]arkets vary with regard to the period of time which is allowed to the forces of demand and supply to bring themselves into equilibrium with one another, as well as

[1] There is a richness in the treatment of time in pairwise models, whether contract theory or game theory, which is not present in treatments of coordination with large numbers. This includes, for example, reliance, renegotiation, information arrival. Similarly, there is a significant time dimension in some attempts to develop more realistic models of individual choice (e.g., Ainslie (1992), Strotz (1955), Schelling (1984), and the collection edited by Loewenstein and Elster (1992)).

with regard to the area over which they extend. And this element of Time requires more careful attention just now than does that of Space. For the nature of the equilibrium itself, and that of the causes by which it is determined, depend on the length of the period over which the market is taken to extend. We shall find that if the period is short, the supply is limited to the stores which happen to be at hand: if the period is longer, the supply will be influenced, more or less, by the cost of producing the commodity in question; and if the period is very long, this cost will in its turn be influenced, more or less, by the cost of producing the labour and the material things required for producing the commodity. These three classes of course merge into one another by imperceptible degrees. (1948, p. 330)

This distinction among temporary, short- and long-period equilibria is familiar and is a staple of textbooks. Marshall defined them as follows:

Marginal title: Classification of problems of value by the periods to which they refer.

Four classes stand out. In each, price is governed by the relations between demand and supply. As regards *market* prices, Supply is taken to mean the stock of the commodity in question which is on hand, or at all events "in sight." As regards *normal* prices, when the term Normal is taken to relate to short periods of a few months or a year, Supply means broadly what can be produced for the price in question with the existing stock of plant, personal and impersonal, in the given time. As regards *normal* prices, when the term Normal is to refer to *long* periods of several years, Supply means what can be produced by plant, which itself can be remuneratively produced and applied within the given time; while lastly, there are very gradual or *Secular* movements of normal price, caused by the gradual growth of knowledge, of population, and of capital, and the changing conditions of demand and supply from one generation to another. (1948, pp. 378–9)

Marshall states clearly and convincingly why he feels the need to divide the analysis into separate considerations of different lengths of time:

The element of time is a chief cause of those difficulties in economic investigations which make it necessary for man

> with his limited powers to go step by step; breaking up a complex question, studying one bit at a time, and at last combining his partial solutions into a more or less complete solution of the whole riddle.... The more the issue is thus narrowed, the more exactly can it be handled: but also the less closely does it correspond to real life. Each exact and firm handling of a narrow issue, however, helps towards treating broader issues, in which that narrow issue is contained, more exactly than would otherwise have been possible. With each step ... exact discussions can be made less abstract, realistic discussions can be made less inexact than was possible at an earlier stage. (1948, p. 366)

Marshall recognized a difficulty in his division of time in that long-period analysis does not produce a theory of actual prices. Instead, as quoted above, he referred to the prices generated by long-period analysis as normal prices, and normal prices need not equal average prices over any particular interval:

> Thus we may emphasize the distinction already made between the average price and the normal price. An average may be taken of the prices of any set of sales extending over a day or a week or a year or any other time: or it may be the average of many such averages. But the conditions which are normal to any one set of sales are not likely to be exactly those which are normal to the others: and therefore it is only by accident that an average price will be a normal price; that is, the price which any one set of conditions tends to produce. In a stationary state alone, as we have just seen, the term normal always means the same thing: there, but only there, "average price" and "normal price" are convertible terms. (1948, p. 372)

To see what has become of the distinction between short and long runs, let me summarize the presentation of this issue in David Kreps' recent textbook, from which I taught this winter. Like Marshall, Kreps identifies three different models, although his trichotomy is different from Marshall's:

> We imagine that firms begin with some initial levels of the factor inputs, some of which can be adjusted in the "short run," while others can only be adjusted in the "intermediate run."

> Breaking time in this fashion, into a short run and an intermediate run and then partitioning the factor inputs into those that are short-run adjustable and others that are intermediate-run adjustable is hardly realistic. It would be more realistic to suppose that some of the firms can change the levels of all their factor inputs quickly, while others may be able to change very little until a lot of time has elapsed. Still, we explore what will happen in this market in the short and in the intermediate run, assuming that these time frames are meaningful and apply to all firms in the industry, and assuming that what is fixed in the short run for one firm is fixed in the short run for all. (1990, p. 269)

> We continue to elaborate the theory by adding a long-run time frame ... In the long run, firms can enter and/or leave this industry: Firms that are in the industry are assumed to depart if at equilibrium prices they are sustaining losses. And firms will enter the industry if at equilibrium prices they can make strictly positive profits. (1990, p. 271)

In other words, Marshall identified a very short run where the supplies on hand were given – a vertical supply curve. He recognized that such a period might not have great relevance for storable items. Kreps skips this period and moves into a discussion where the number of firms is given, but there are different cost curves, depending on the set of adjustable factors, as opposed to historically given factors.

Thus, in approaching the modeling of time, the first step in both Marshall and Kreps is to distinguish the time frames for which the models are relevant. The second step in both books is then to use atemporal models. That is, in neither the long-run nor the short-run model does time enter explicitly. Instead, a model in which time does not appear explicitly is made to refer to different time frames by adjusting the range of allowed behaviors of economic agents. The short-run model differs from the long-run model by having fewer variables (and more parameters). In this way, we accommodate Marshall's "limited powers" of human analysis.

For Marshall, the different periods are devices for

simplified mathematical analysis of different factors affecting equilibrium. That is, simple models are used to illustrate how economic forces work. A short-run model is meant to describe how the levels of variable inputs respond to a change in circumstances that happened very shortly before the time being analyzed. A long-run model is meant to describe how slow-moving variables respond to changed circumstances that happened considerably before the time being analyzed.[2] Both models are pedagogic about forces. In this sense, neither model is about equilibrium – both models are about the working of forces.[3] While such an interpretation of the models is possible, it tends to defeat the purpose of building equilibrium models, which is to incorporate the feedback elements in the examination of the response of a system to circumstances.

An alternative way to think about these models, and one that probably reflects how people use the models in thinking about the economy, is that the models are meant to be models about equilibrium. More specifically, the models are about changes in equilibrium–comparative statics. From this perspective the short-run model is meant to answer the question of how equilibrium will change a short while after a (sort-of-permanent) change in some

[2] Difficulty in analyzing processes where different factors move at different speeds is not unique to economics. For example, Andrew Solow (1991) has written: "In order to model climate realistically, it is necessary to couple the ocean and the atmosphere into an overall model. The main difficulty in doing so arises from the great disparity between atmospheric time scales (on the order of one day) and oceanic time scales (on the order of one year to one millennium). So-called synchronously coupled ocean-atmosphere models are prohibitively time-consuming to run except with an unrealistic atemporal ocean model. Various tricks have been employed to use asynchronous coupling as a way of accelerating convergence, but the problem remains unsolved" (p. 15).

With this interpretation, thinking about the economy requires the intuitive combination of several simple models. One of the great difficulties in economic analysis is the process of going from abstract analysis to thinking about the economy. That is, how does one use what one has learned from abstract analysis. The easy way out is to take the model literally. Sometimes, this seems to be what is meant by taking a model seriously. To me, taking a model seriously means putting in the effort to think through what lessons from the model one wants to take along when thinking about the economy.

parameter. Similarly, the long-run model is meant to describe how equilibrium will be different a long time after a change in some parameter.

In this setting, one can ask about the omissions (and possibly errors) from the way that time is treated. In fact, both short-run and long-run factors are working all the time. Does it matter that firms are continuously entering and exiting in trying to understand the short-run response of equilibrium? Does it matter that there are repeated short-run shocks when thinking about the long run of an industry? (This question might be phrased as asking about the difference between Marshall's normal price and Marshall's average price.) Are there questions that are omitted because of the usual way the analysis is divided into tractable parts?

As a contrast with this familiar use of atemporal models with different constraints, I want to present a model with explicit consideration of time. Since I am not trying to answer some particular question, but just trying to indicate how the analysis flows differently (gives different answers, directs attention to different research questions), I will use a simple model of these same phenomena. The ingredients I want to emphasize are explicit treatment of time, repeated occurrence of random events, and constant presence of both output adjustment by individual firms and entry and exit of firms.

But this choice of ingredients raises another issue in Marshall's analysis. Marshall relies on a further analytic simplification in long-period analysis by the use of the "representative firm." That is, Marshall felt that it was adequate to ignore the patterns of growth and decline of individual firms:

> At any particular moment some businesses will be rising and others falling: but when we are taking a broad view of the causes which govern normal supply price, we need not trouble ourselves with these eddies on the surface of the great tide. (1948, p. 378)

> Let us call to mind the "representative firm"... let us assume that the normal supply price of any amount of that

> commodity may be taken to be its normal expenses of production...by that firm. (1948, p. 342)

I will follow a modeling strategy that implies dropping the representative firm as used by Marshall. Thus I am asking about the importance of what Marshall called the "eddies" when one is thinking about events that will occur some time in the future. First I will describe a simple example of a model that tries to come to grips with some of the issues of modeling time explicitly. Then I will turn to empirical work to underscore the importance of simultaneous consideration of these different factors.

1.2 Job creation and job destruction

I turn now to a simple model where firms have different (and stochastic) experiences, although the industry as a whole has a determinate equilibrium. The model is a simplified version of models developed by Boyan Jovanovic (1982) and S.A. Lippman and R.P. Rumelt (1982).[4] The model will give an example of how short-run uncertainties are important for long-run equilibrium and of how the long-run entry and exit factors can dominate short-run responses.

Entry

If we are to construct a model with explicit time, we need to consider the modeling of the set of potential firms available at any point in time. That is, in a timeless model, there is assumed to be some set of potential entrants. In the short-run model above, the set was empty. In the long-run model, there was some set of potential firms, perhaps all identical. In an explicit-time model, we need to consider

[4] For an extensive discussion of competitive equilibrium with uncertainty and irreversible investment, see Dixit and Pindyck (1994). For another model of continuous job creation and job destruction, but coming from continuous technical progress, see Caballero and Hammour (forthcoming). That paper, like this presentation, considers the behavior of entry and exit in response to fluctuations in industry demand.

the availability of potential entrants at each point in time. This involves answering two questions. One is whether the flow of new potential entrants is made up of *ex ante* identical firms. The second is whether a potential entrant that does not enter continues to be available in the future. That is, do we model potential entrants as a repeated flow or as a stock that grows when actual entry is below the flow of potential entry. The stock model has considerable appeal, particularly if combined with the disappearance of some of the potential entrants who do not enter. For simplicity, however, I will use the alternative assumption of a flow of potential entrants, who disappear from the model if they do not enter in the period in which they become available.

Since it seems realistic and is important for the analysis, I will assume an upward sloping supply curve of potential entrants. That is the expected rate of profit needed to induce entry will vary across potential firms. To begin, I will focus on steady-state models, and then consider time-varying models that preserve the anticipated profitability of the steady state. Thus, it is easy to calculate present discounted values, without detailed concern with the formulation of expectations.

I will take the supply curve of entrants in a period as available that period in response to anticipated conditions in that period. Thus, I am modeling the entry process, from the decision to enter until actual entry, as instantaneous, with no lags associated with entry. Realistically, the process of entry takes time, with firms in the process of entering able to speed up or slow down this process. Realistic modeling would be complicated, and I make the conventional simplifying assumption.

Uniform costs

To present the basic structure, I start with a model where all firms are the same *ex post*. There is a supply curve, $S(k)$, of firms willing to enter if the expected present discounted value of profits exceeds their cost of entry, k. As I said, if a potential firm does not enter it disappears; potential