THE STRUCTURE OF DISEQUILIBRIUM MODELS

Richard E. Quandt

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PRINCETON UNIVERSITY
207 Dickinson Hall
Princeton, New Jersey

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1. Introduction

The notion of equilibrium has been a cornerstone of economics for a very long time. It has been an enormously useful concept that has, among others, permitted a variety of comparative statics analyses of micro as well as of macro phenomena. Although one may argue about the precise connotation of "equilibrium", for operational purposes we take it to refer to a situation in which prices clear markets: prices are such that neither buyers nor sellers have reasons to attempt to recontract.

The quantity-rationing or disequilibrium models stand in fairly sharp contrast to the equilibrium paradigm. It is not my intention here to engage in extended Dogmengeschichte but simply note that Keynesian theory is an obvious early example of a model in which markets do not necessarily clear. It is, of course, formally easy to form a paradigm that is different from equilibrium by simply asserting that, for whatever reason, prices are rigid and that the Walrasian auctioneer cannot function. But denial of price flexibility, simple as that notion

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may be, brings with it a host of difficulties in problem formulation, model specification and estimation.

The recent literature on disequilibrium has become voluminous enough to warrant some self-examination and some general reflections. These will form the central purpose of the present paper. We conclude this introduction with three general observations.

(1) The debate between protagonists of the equilibrium paradigm and the disequilibrium paradigm has a strong ideological flavor. Proponents of one view frequently think that the alternative view is worthless or perhaps downright silly. A few years ago I gave several seminars on the question of how one would test the null hypothesis that a set of observations is better explained as having been generated from an equilibrium specification (Quandt (1978b)). On some of these occasions (mostly in the U.S.) I would be interrupted by someone five minutes into the seminar with the remark, "What you are trying to do is silly, because everybody knows that prices always clear markets and therefore there is nothing to test". At other times (mostly in Europe) I would be interrupted with the remark, "What you are trying to do is silly, because everybody knows that prices never clear markets and therefore there is nothing to test". Juxtaposing the two remarks very much convinced me that there definitely is something to test and that any approach that is not ultimately willing to subject such questions to <u>data</u> as the final arbiter must be profoundly misguided.

(2) The recent disequilibrium literature (in the broadest sense) has at least five distinct strands. These may be identified as (a) the macro-disequilibrium literature à la Barro and Grossman (1971), Malinvaud (1977),

to abstract from extraneous considerations, in spite of the fact that the most interesting empirical advances are likely to occur in models of several interrelated markets. Much of what we shall say applies, mututis mutandis, to simultaneous market models as well.

2. Concepts of Equilibrium, Disequilibrium and Some Basic Models

The Basic Models. We introduce in the present section the most frequently encountered varieties of disequilibrium models for a single and isolated market. Examples of empirical models of this type are found in Fair and Jaffee (1972), Laffont and Garcia (1977), Rosen and Quandt (1978), Portes and Winter (1980), MacKinnon and Olewiler (1980), and others. Typical in such models is the presence of a demand function, supply function and a "min condition":

$$D_t = \alpha_1 p_t + \beta_1' x_{1t} + u_{1t} \qquad (2\text{-}1)$$

$$S_t = \alpha_2 p_t + \beta_2' x_{2t} + u_{2t} \qquad (2\text{-}2)$$

$$Q_t = \min(D_t , S_t) \qquad (2\text{-}3)$$

where x_{1t} , x_{2t} are vectors of exogenous variables, u_{1t} , u_{2t} are error terms (customarily assumed to be jointly normal with mean vector zero, covariance matrix Σ , and serially uncorrelated) and where D_t and S_t are unobserved by the econometrician but Q_t is observed. If (2-1) to (2-3) represent the full model, the price of the commodity p_t must also be taken to be exogenous and the only observable random variable in the model is Q_t . Equs. (2-1) and (2-2) are normally derived from choice theoretic considerations; thus in an analysis of an aggregate labor market

Rosen and Quandt (1978) derive the demand function from firms' profit maximizing behavior and the supply function from workers' utility maximization. Equ. (2-3) is customarily justified on the basis that exchange is voluntary: no potential purchaser can be made to buy more than he wishes, nor can a supplier be made to sell more than he desires.

The basic model (2-1) to (2-3) is frequently supplemented by a price adjustment equation of the form

$$p_t = p_{t-1} + \gamma(D_\tau - S_\tau) + u_{3t} \tag{2-4}$$

where τ is taken to be either t or $t-1$, where u_{3t} is either identically zero or is itself normally distributed (jointly with u_{1t}, u_{2t}) and where γ may be specified to have different values γ_1, γ_2 according to whether $D_t > S_t$ or $D_t \leqq S_t$. It is clear that Equ. (2-4) introduces dynamic elements into the model; detailed consideration of this is deferred to Section 3.

Essential Features of the Basic Model. Although the model given by (2-1) to (2-3) or the fuller model including (2-4) as well accounts for a majority of single-market disequilibrium formulations encountered in the literature, some models have a slightly different structure.[2] All models in this general class share, however, the following (related) characteristics (1) They contain inequalities as essential ingredients, since the min condition (2-3) could be written as "$Q_t = D_t$ if $D_t \leqq S_t$ and $Q_t = S_t$ if $D_t > S_t$". (2) Some agents whose behavior the model purports to represent are usually

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2. See Goldfeld and Quandt (1975) and Goldfeld, Jaffee and Quandt (1980) dealing with an agricultural market and a financial market respectively. For a more detailed review see Quandt (1982).

"off their behavioral curve". It is clear, for example, that in (2-1) to (2-3) either demanders or suppliers will be off their curves except on a set of measure zero. The consequence of this is that some endogenous variables in the model are not observed but latent. This creates a strong family resemblance between disequilibrium models and other latent variable models such as the switching regression model, the probit model or the tobit model. In fact, one may show the similarities by a formalization due to Kiefer (1978) and to Poirier and Ruud (1981) as follows:

Let

$$\begin{aligned} y_t &= \beta_1' x_{1t} + u_{1t} \quad \text{if} \quad z_t > 0 \\ y_t &= \beta_2' x_{2t} + u_{2t} \quad \text{if} \quad z_t \leqq 0 \\ z_t &= \beta_3' x_{3t} + u_{3t} \end{aligned} \tag{2-5}$$

If z_t is set equal to $\beta_2' x_{2t} - \beta_1' x_{1t} + u_{2t} - u_{1t}$, (2-5) is the canonical disequilibrium model (2-1) to (2-3). If x_{3t} were a set of constants invariant with respect to t, it becomes a switching regression model (Quandt (1972), Quandt and Ramsey (1978)). If $u_{1t} = u_{2t} = 0$, $\beta_1' x_{1t} = 1$, and $\beta_2' x_{2t} = 0$ for all t, the model reduces to the standard probit model. If, finally, $\beta_1' x_{1t} + u_{1t} = \beta_3' x_{3t} + u_{3t}$ and if $\beta_2' x_{2t} = 0$ for all t, it is the well-known tobit model.[3]

It is useful to note the similarity between these models, since

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3. Considerable variations exist in just what is latent in a model. Concentrating on the disequilibrium model alone, we may note that if $u_{3t} \equiv 0$ in Equ. (2-4), then the observed prices perfectly classify the data into excess demand and excess supply periods. In this case, the investigator does observe D_t in some periods (but not S_t) and S_t (but not D_t) in others and, moreover, he knows when he is observing D_t and S_t. If $u_{3t} \not\equiv 0$, he does not even know whether excess demand or excess supply has occurred and cannot identify any observation as demand or as supply with certainty.

they share certain econometric properties. We shall not dwell at length here on technical properties and estimation methods. I shall only summarize of the salient features. For details the reader is referred to Maddala and Nelson (1974), Laffont and Monfort (1976), Quandt (1978), Gourieroux, Laffont and Monfort (1980a, 1980b) and Quandt (1982). The principal econometric features are as follows: (1) Estimation is most frequently by maximum likelihood, although in special cases two-stage least squares methods are available; (2) The likelihood functions tend to be unbounded in parameter space; a feature that may create severe computational problems and is shared by the switching regression model and (in special cases) by the tobit and logit models; (3) The likelihood functions contain integrals of density functions, with the multiplicity of the integrals depending on the number of observed endogenous variables; thus in a disequilibrium model with two interrelated markets (or in a probit model with two related probit variables) double integrals occur in the likelihood function. Given the state of the art in numerical integration (Quandt (forthcoming)), this creates serious computational problems in estimating sizeable models.

Although estimation of models of the kind discussed above has been reasonably successful, they have been criticized on various grounds. We now turn to a discussion of various criticisms.

Effective Demand and Equilibrium Concepts. A principal question in any discussion of the possibility of disequilibrium is the question of the logical consistency between our ordinary concepts of demand and supply functions on the one hand and the notion of disequilibrium on the other. Hendry and Spanos (1980) have discussed their concerns over this issue at some length.

There are at least two basic considerations: (1) Demand and supply functions, being derived from utility maximization for consumers and profit (or output) maximization for firms, are static and timeless, and represent intentions to buy or sell. As such, they have no meaning at points other than the equilibrium point; i.e. at prices other that the price that satisfies

$$D(p) = S(p) \tag{2-6}$$

Under these circumstances, demand and supply functions cannot "explain" equilibrium; at best they can define it (and, of course, exhibit the dependence of equilibrium price and quantity on the various exogenous variables that might be included in (2-6)). (2) Nothing is included in (2-6) that can tell us how a market may move from one equilibrium to another (following, perhaps, an unexpected shift in some exogenous variable). In other words, what is needed is a theory of how plans are formed by the various agents in the market and how plans are revised in the light of new information. Both observations have a lot of merit; yet neither criticism is fatal and solutions to the problems raised have been under active investigation for some time.

As to the first problem, we may note immediately that what is relevant is not the notional, Walrasian demands and supplies but effective demands and supplies that take into account rationing in the various markets. More formally, consider a consumer with utility function $U(c,\ell)$, where c is consumption goods, ℓ the amount of labor and assume that he maximizes U subject to a budget constraint $m_0 + w\ell \geqq pc$ (where w is the wage,

p represents consumer prices and m_0 is nonlabor income). The resulting demand and supply functions are $D = D(p,w,m_0)$, $S = S(p,w,m_0)$. If, however, additional constraints are present such as $\ell \leqq \bar{\ell}$, where $\bar{\ell}$ limits the amount of labor that the consumer may sell, an amended optimization problem must be solved and the resulting demand function for consumer goods, $D(p,w,m_0,\bar{\ell})$, will in general, be a function of $\bar{\ell}$ as well. Thus, the effective demand for consumer goods contain a spillover from the labor market: the rationing imposed in the latter affects desired purchases in the former.

There is an important difference of opinion as to the precise manner in which this contrained optimization comes about (Benassy (1977), Svensson (1980)). Drèze demands (Drèze (1975)) are derived if the utility function is maximized subject to the budget constraint and all quantity constraints that exist. Clower demands (Clower (1965)) are obtained if the utility function is maximized subject to the budget constraint and all quantity constraints except the one relevant for the commodity the demand for which is to be derived. Thus, letting x be a vector of n goods, $\bar{x}$ the vector of quantity constraints and m_0 the initial endowment of money, Drèze demands are obtained by solving the following (single) optimization problem:

$$\max_x \; U(x) \qquad \text{subject to} \quad p'x \leqq m_0 \; , \; x \leqq \bar{x} \tag{2-7}$$

The Clower demands are obtained by solving optimization problems for $i=1,\ldots, n$

$$\max_x \; U(x) \qquad \text{subject to} \quad p'x \leqq m_0 \; , \; x_j \leqq \bar{x}_j \quad \text{for} \quad j \neq i \tag{2-8}$$

The effective demand vector in the first case is simply the solution of (6-1). The effect demand vector in the second case is formed by the vector which has as its ith component the ith component of the ith optimization problem of type (6-2).

It is curious that neither of the two demand concepts is fully satisfactory. If Drèze demands are employed, there can be no discrepancy between actual trades and effective demands, which is counterintuitive. On the other hand, Clower demands need not satisfy the budget constraint. Moreover, the computation of Clower demands posits a sequential optimization procedure which is also counterintuitive. Svensson (1980) finds on balance that the choice theoretic foundations of Clower demand are weak. The effective demand concept introduced by Svensson is based on the view that rationing is a stochastic matter--a formulation that appears to be more congenial to econometric formulations than either the (deterministic) Drèze or Clower demands. He derives the effective demand as that demand which maximizes expected utility subject to the constraint that for each rationing configuration which has nonzero probability of occurring, the actual trades satisfy the budget constraint.

Although the Clower demand concept seems to predominate in practice in spite of its disadvantages (Barro and Grossman (1971), Malinvaud (1977), Ito (1980), Gourieroux, Laffont, Monfort (1980a)), the upshot is that the issue of which demand (and supply) concept is most appropriate for treating disequilibrium must be considered to be an open question. Hendry and Spanos are right in pointing out the unsettled and unsatisfactory state of affairs.

Two related points emerge from the work of Kornai (1979). The first one is the claim that shortages cannot be described or measured by macro-aggregates, particularly if the shortage grows chronic, since individuals adapt to shortages by substituting other goods. In terms of *effective* demands and supplies one would therefore expect less disequilibrium to be observed than in terms of notional demands and supplies. But for Kornai's point to be entirely valid, we would not only need pervasive rational expectations of ration quantities but consumers would have to anticipate random errors as well--a much too strenuous requirement. The second point is that in the presence of "soft" budget constraints that may characterize some enterprises in socialist economies, the usual microeconomics breaks down and, I believe, by implication supply functions are not well defined. But this is precisely the point at which a Svensson-type effective demand-supply concept is likely to be relevant and helpful. It surely is not plausible to argue that enterprises perceive absolutely no constraints. What is much more plausible is that with very small probability they see themselves unencumbered by constraints, with some other probability they see themselves slightly more constrained, etc. Such a stochastic view of constraints will rescue a somewhat more traditional framework and allow us to treat disequilibrium in it.

Hendry and Spanos' second point is also important. They note the absence of an adequate dynamic theory. This, of course, is not inherent in the analysis of demand and supply; demand functions can just as well be thought of as being derived from lifetime utility maximization. But in practice, demand functions employed tend to be static and the dynamics (such as Equ. (2-4)) grafted onto the analysis often has an *ad hoc* flavor. These issues will be discussed further in Section 3.

Disequilibrium or Partial Adjustment? Disequilibrium models which include a price adjustment equation such as (2-4) have a superficial similarity to the well-known partial adjustment models. The latter may be formulated (in one of several ways) as

$$p_t^* = \beta' x_t + u_t \tag{2-9}$$

where p_t^* is defined as the equilibrium value of p_t and, say,

$$p_t - p_{t-1} = (1-\lambda)(p_t^* - p_{t-1}) \tag{2-10}$$

representing the partial adjustment. However, by substituting (2-1) and (2-2) into (2-4), the disequilibrium model may also be written in the form (Bowden (1978a), (1978b)) as

$$\begin{aligned} p_t &= \frac{1}{1+\gamma(\alpha_2-\alpha_1)} p_{t-1} + \frac{\gamma(\alpha_2-\alpha_1)}{1+\gamma(\alpha_2-\alpha_1)} p_t^* + \frac{u_{3t}}{1+\gamma(\alpha_2-\alpha_1)} \\ &= \mu p_{t-1} + (1-\mu) p_t^* + v_t \end{aligned} \tag{2-11}$$

which is formally indistinguishable from (2-10) if u_{3t} (and hence v_t) is zero. The partial adjustment approach is employed, for example, by Orsi (1981).

It seems hardly worthwhile to engage in terminological disputes as to whether our basic formulation or the partial adjustment model captures the essence of disequilibrium in a more unambiguous fashion. They rest on different assumptions and have different econometric implications. The min condition in the basic model achieves its plausibility from the assumption of voluntary exchange (see e.g. Malinvaud (1977)): no buyer can be forced to purchase more than he wishes to, not can a seller be forced to sell more than desires. Yet, Rosen and Quandt (1978) question its appropriateness in situations in which buyers and sellers do not have equal market power and where the assumption of voluntary exchange may not be fully tenable. On the other hand, the partial adjustment mechanism is only one of many possible dynamic specifications such as autoregressive error models, error correction mechanisms, etc. (Hendry and Richard (1981)). It represents a very particular and mechanical approach to adjustment. Whether one or the other of these approaches will ultimately be more successful is largely an empirical proposition; it would be very desirable to perform some systematic comparisons between the two approaches.[4]

Alternative formulations of the Basic Model. Within the basic framework several alternatives have been suggested. Muellbauer (1978) introduced the idea, particularly relevant to labor markets, that the observed quantity is an aggregate of corresponding quantities from numerous local markets. Assume that markets are indexed by j . Defining D and S as the average demand and supply, we can write for the jth market.

$$D_j = D + \varepsilon_{1j}$$
$$S_j = S + \varepsilon_{2j} \tag{2-12}$$

where ε_{1j} , ε_{2j} have zero means and a joint distribution function $F(\varepsilon_{1j},\varepsilon_{2j})$. The min condition applies to each individual market. The jth market has excess demand if $D_j - S_j > 0$, or if $z \equiv D - S > \varepsilon_{2j} - \varepsilon_{1j} \equiv \theta$. The average

4. One could, and to my knowledge this has not been done, generate data in Monte Carlo experiments from each of the two approaches and then estimate parameters using both the correctly specified as well as the misspecified approaches. This ought to reveal a great deal about the costs of misspecification.

aggregate value of the observed quantity Q is the sum of demands over markets in which there is excess supply plus the sum of supplies in markets in which there is excess demand. Thus

$$Q = \int\int_{\theta \geq z} (D+\varepsilon_1)\,dF(\varepsilon_1,\varepsilon_2) + \int\int_{\theta < z} (S+\varepsilon_2)\,dF(\varepsilon_1,\varepsilon_2) =$$

$$= D(1-P) + SP + \int\int_{\theta \geq z} {}_1 dF(\varepsilon_1,\varepsilon_2) + \int\int_{\theta < z} \varepsilon_2\,dF(\varepsilon_1,\varepsilon_2) \tag{2-13}$$

where $P = \int\int_{\theta < z} dF(\varepsilon_1,\varepsilon_2)$ is the probability of excess demand. Equ. (2-13) can be written as

$$Q = D + H(z) \quad \text{or} \quad Q = S + G(z) \tag{2-14}$$

where $H(z)$ and $G(z)$ are functions that can in principle be determined from the assumptions about the joint distribution of ε_1 and ε_2. If D (or S) and z can be modelled as functions of independent variables and if some error structure is assumed for (2-14) (say, additive errors), the parameters of (2-14) can in principle be estimated by nonlinear least squares. The locus of Q points given by (2-14) lies at each value of the price p to the left of the straight-line segments given by $Q = \min(D,S)$. Whether this formulation will ultimately be useful remains to be seen. The H or G functions may be intractable and formulation of such a model requires one to specifically model excess demand rather than allow excess demand to emerge from the logic of the behavioral equations.

An alternative modification is due to Tischler and Zang (1979) and

Sneessens (1979, 1981). According to this the disequilibrium model is written as

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\begin{aligned}
D_t &= \alpha_1 p_t + \beta_1' x_{1t} \\
S_t &= \alpha_2 p_t + \beta_2' x_{2t} \qquad (2\text{-}15) \\
Q_t &= \min(D_t, S_t) + v_t
\end{aligned}
$$

It may be interpreted either as requiring demand and supply to be exact or as having the min condition apply to expected demand and supply. It turns out that the likelihood function for (2-15) is quite different from that corresponding to (2-1) to (2-3). It may in practice often be maximized, sometimes more easily than the likelihood function corresponding to the standard disequilibrium. Sneessens (1981) in limited Monte Carlo experiments finds that this model is more robust and produces smaller mean square errors than the standard model. However, the model does contain some features that call in question its usefulness. Such a conceptual feature is the very specification of the demand and supply functions which do not contain error terms. It is difficult to accept the notion that these functions are exact; i.e., that neither errors in the underlying utility or profit maximizations, nor errors in aggregation, nor errors in specification are present, nor is it very persuasive to argue that Q_t is determined by expected demand and supply. A statistical difficulty is that over large subsets of the parameter space some of the parameters are not identified. This is in contrast to the standard model in which the parameters remain identified (although as a practical matter identification may be hard to achieve). The difference is that in the standard model the regime which is never in effect has a (slight) effect on the likelihood whereas in the Tischler-Zang model it has no effect. Next, as one may verify, a computational difficulty is that the likelihood function normally possesses numerous local maxima. Finally, a feature that has conceptual as well as statistical and computational aspects is the following: what happens if the model (2-15) is required to have a price adjustment equation appended to it? Including a price adjustment equation such as $p_t = p_{t-1} + \gamma(D_t - S_t)$ makes prices adjust deterministically to excess (expected) demand which is hardly plausible. If, however, an error term is included in the price adjustment equation, the simplicity of (2-15) is lost anyway. It is thus not clear whether the Tischler-Zang-Sneessens formulation can easily be extended to more complicated models.

Our purpose in which section was not to give an exhaustive account of disequilibrium models but only to identify some major conceptual and technical strands. Many of the criticisms levelled against one or the other formulation may be well founded; at the same time numerous fundamental questions remain open. One of the most important of these is the question of dynamics; how the system behaves over time. This is the question to which we now turn.

3. Dynamics and Adjustment Equations

In order to characterize the evolution of a system over time, one needs to specify dynamic equations in which time or lags play an essential role. This requires one to specify the variables that perform the adjustment as well as the variables that trigger the adjustment. It is probably fair to observe that the theoretical foundations of dynamic specification are much weaker than static theories. Unlike the physical sciences in which theories are, ab initio, often formulated in terms of first and higher order derivatives, the most common versions of utility and profit maximization are essentially static in character. This leads to the appearance of dynamic equations that often have an ad hoc character.

The Basic Model. The standard procedure for introducing dynamics into the model given by Equs. (2-1) to (2-3) is to append (2-4) which we rewrite for convenience,

$$p_t = p_{t-1} + \gamma(D_t - S_t) + u_{3t} \tag{3-1}$$

where we adopt the convention that the excess demand on the right hand side is contemporaneous and the error term not identically equal to zero. This equation has provoked a fair amount of controversy. On the one hand, one must admit that, unlike the demand and supply functions, the price adjustment equation is not nearly as well rooted in choice theoretic considerations. Yet the use of (3-1) has hoary antecedents in that the treatment of dynamics in the perfectly competitive model has traditionally assume that $\dot{p} = k(D-S)$. If this is to represent the behavior of the mythical auctioneer, one may ask whether the assumption makes sense in a realistic context. If (3-1) is taken to represent a real process in discrete time, one may ask what is being implied with respect to trading at nonequilibrium prices and how such trading might affect the underlying demand and supply relationships. What is needed is a derivation of the relevant dynamics from some optimization process. Thus Barro (1972) and Upcher (1980) argue that price adjustment equations of comparable sort may be derived from the assumption that the system acts so as to minimize certain adjustment costs. It is reasonably plausible to assume the existence of such cost-minimizing procedures although much needs to be done in order to determine which are the most promising members of this class. For example, if one assumed that adjustment costs are due to price change and to the presence of disequilibrium, the cost function might be written as

$$C = (p_t - p_{t-1})^2 + \theta(D_t - S_t)^2 \tag{3-2}$$

Minimizing with respect to p_t yields

$$p_t = p_{t-1} + \theta(D_t' - S_t')(D_t - S_t)$$

Even with cost minimization, the standard price adjustment equations (2-4) is correct only if the demand and supply functions are linear. Now assume that an additional adjustment cost is incurred as a result of changing the planned supply of commodities. The cost function now is

$$C = (p_t - p_{t-1})^2 + \theta_1(D_t - S_t)^2 + \theta_2(S_t - S_{t-1})^2 \tag{3-3}$$

and the minimization with respect to p_t yields

$$p_t = p_{t-1} - \theta_1(D_t' - S_t')D_t + [\theta_1(D_t' - S_t') - \theta_2 S_t']S_t + \theta_2 S_t' S_{t-1} \tag{3-4}$$

which even with linear demand and supply functions, does not look at all like (3-1). The only thing (3-1) and (3-4) have in common is that, with normal assumptions about the slopes of demand and supply functions, D_t has a positive and S_t a negative coefficient. In general, model building along these lines may turn out to be fruitful and is likely to lead to dynamics that have less of an *ad hoc* flavor.

The Hendry-Spanos Modification. There are instances in the literature where the simple version (2-4) was deemed inadequate. Rosen and Quandt (1978), dealing with an aggregate US labor market write the analogue of (3-1) as $w_t = w_{t-1} + \gamma_1(D_t - S_t) + \gamma_2 V_t + u_{3t}$ where w_t refers to wages and V_t is a variable measuring the extent (or rate of change) of unionization. But this is a minor change compared to that suggested by Hendry and Spanos (1980) who, following Frisch (1949), propose a more elaborate dynamic specification. Consider the demand and supply functions as given by (2-1) and (2-2) and supplement them with the following two equations[5]

$$p_t = \gamma_0 + \gamma_1 p_{t-1} + \gamma_2(Q_t - D_t) + \gamma_3(S_t - Q_t) + v_{1t} \tag{3-5}$$

$$Q_t = \delta_0 + \delta_1 Q_{t-1} + \delta_2(p_t - p^d(Q_t)) + \delta_3(p^s(Q_t) - p_t) + v_{2t} \tag{3-6}$$

where $p^d(\ )$ and $p^s(\ )$ are the inverses of (2-1) and (2-2) respectively. No specific assumption is made about how Q_t is determined except by (3-6):

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5. The present formulation differs from that of Hendry and Spanos in two respects: (1) They include inventories in (3-5) and (3-6), the omission of which has marred many previous disequilibrium models. We feel comfortable, however, with the omission of inventories here since we have a labor-market application in mind. (2) Hendry and Spanos distinguish between theoretical variables and observed variables; the latter being the former plus an error term. We rewrite their formulation entirely in terms of observed variables and include composite error terms in the equations.

the actual quantity in any period depends on its previous value and the excess of the actual price over the demand and supply prices corresponding to that value of Q_t .

There is no doubt that (3-5) and (3-6) are very flexible formulations. Hendry and Spanos point out that if one imposes the restrictions $\gamma_2 = \gamma_3$, $\delta_2 = \delta_3$, $\gamma_1 = \delta_1 = 1$, one obtains an error correction mechanism containing derivative correction, integral correction and equilibrating adjustment. Yet it is not clear exactly what kind of behavior is implied by (3-5) and (3-6). If, for example, $\gamma_2 = \gamma_3$, then (3-5) resembles (2-4) and we may confidently expect $\gamma_2 (= \gamma_3)$ to be negative. But if $\gamma_2 \neq \gamma_3$, what are we to expect?

In Table 1 we report the results of some illustrative calculations based on the model of Rosen and Quandt of an aggregate US labor market. A slightly simplified form of this model is

$$\ell nD_t = \alpha_0 + \alpha_1 \ell nw_t + \alpha_2 \ell nX_t + \alpha_3 t + u_{1t} \tag{3-7}$$

$$\ell nS_t = \beta_0 + \beta_1 \ell nw_{nt} + \beta_2 \ell nP_t + u_{2t} \tag{3-8}$$

$$\ell nQ_t = \min(\ell nD_t, \ell nS_t) \tag{3-9}$$

$$\ell nw_t = \ell nw_{t-1} + \lambda_1(\ell nD_t - \ell nS_t) + \lambda_2 + u_{3t} \tag{3-10}$$

where w_t is total wages and salaries in the US private sector in 1958 dollars divided by the number of private hours worked, $w_{nt} = w_t(1-\theta_t)$ where θ_t is the ratio of personal taxes to personal income, X_t is GNP in 1958 dollars and P_t is the potential number of hours worked and equals the civilian population between 16 and 64 multiplied by the average annual hours worked. The period covered was 1929-1973. Table 1 contains the results for this model (Column 1) and for four version of the model specified in (3-5) and (3-6). The models in Cols. 3, 4, 5 and 6 are nested with respect

Table 1. Disequilibrium Estimates*

Coefficient	Model (3-7) to (3-10)	No restrictions	Model (3-5), (3-6)** $\delta_1 = \delta_1 = 1$	$\gamma_2 = \gamma_3$	$\delta_2 = \delta_3$	$\delta_1 = \gamma_1 = 1,\ \gamma_2 = \gamma_3,\ \gamma_2 = \gamma_3$
α_0	-.455	-	-	-	-	-
	(.066)					
α_1	-.477	-.756	-.633	-3.562	-.347	-2.495
	(.070)	(.093	(.086)	(.927)	(.064)	(.334)
α_2	.948	.790	.903	4.412	.894	.565
	(.010)	(.031)	(.002)	(.879)	(.113)	(.245)
α_3	-.011	.003	-.003	-.011	-.003	.007
	(.002)	(.003)	(.003)	(.009)	(.004)	(.014)
β_0	-1.609	-	-	-	-	-
	(.033)					
β_1	-.189	-.210	-.006	.0000	-.685	.0001
	(.021)	(.113)	(.007)	(.0000)	(.199)	(.0004)
β_2	1.175	1.000	.855	2.341	.646	1.383
	(.006)	(.273)	(.008)	(.744)	(.178)	(.100)
λ_1	.097	-	-	-	-	-
	(.050)					
λ_2	.036	-	-	-	-	-
	(.007)					
γ_1	-	.943	1.000	.945	.588	1.00
		(.028)	-	(.021)	(.173)	-
γ_2	-	-4.221	-2.813	-.077	-1.172	-.311
		(1.224)	(.097)	(.021)	(.210)	(.001)
γ_3	-	-.996	.160	-.077	-.082	-.311
		(.136	(.095)	(.021)	(.178)	(.001)
δ_1	-	1.081	1.000	.503	2.481	1.00
		(.100)	-	(.090)	(.646)	-
δ_2	-	-2.236	-4.084	-.562	-1.515	.0001
		(.588)	(.612)	(.048)	(.461)	(.0003)
δ_3	-	.101	-.004	.0000	-1.515	.0001
		(.066)	(.004)	(.0000)	(.461)	(.0003)
logL	193.40	208.66	200.62	197.40	208.15	182.46

* Asymptotic standard errors in parentheses.

** α_0 , β_0 , γ_0 , δ_0 are not separately identifiable to the model of Col. 2; hence here likelihood ratio tests are possible. Only the model with $\delta_2 = \delta_3$ survives against the general model with no restrictions. Although no choice between Cols. 2 and 5 can be made on likelihood ratio grounds, these two sets of results have vastly different economic implications. If the underlying production function giving rise to (3-7) were CES, we would have $\alpha_1 = -\sigma$, $\alpha_2 = (\sigma h+1-\sigma)/h$, and $\alpha_3 = -\mu\sigma(1-\sigma)/h$, where σ is the elasticity of substitution, h measures returns to scale and μ is the rate of Hicks-neutral technological change. The results derived from Table 1 are in Table 2.

Table 2. Values of σ, h, and μ .

	Model (3-7) to (3-10)	Model (3-5), (3-6): No restrictions	$\delta_1 = \gamma_1 = 1$	$\gamma_2 = \gamma_3$	$\delta_2 = \delta_3$	$\delta_1 = \gamma_1 = 1$ $\gamma_2=\gamma_3$, $\delta_2=\delta_3$
σ	.477	.756	.633	3.560	.347	2.495
h	1.067	7.176	1.359	3.004	1.194	-.775
μ	.055	-1.284	.018	.003	.005	.001

Only the results for the basic disequilibrium model (3-7) to (3-10) and for Col. 5 survive; the others produce absurd results in various degrees. A final comparison may be made on the basis of (within-sample) forecasting abilities of the various models. The basic model predicts that 10 out of the 44 years are excess demand years and the other 34 excess-supply; moreover the excess supplies of labor track the historical unemployment figures quite well. The results of Col. 5 predict excess demand in every year; a highly implausible result. What a model such as (3-5), (3-6) does do well is to track observed employment levels; its ability to predict excess demand leaves a great deal to be desired.[6] Although all practitioners of disequilibrium modelling will agree that the present state of dynamics is inadequate, the Hendry-Spanos modification does not appear to solve the problem.

Rational Expectations in Disequilibrium? A major new insight into price dynamics has been provided in a recent paper by Green and Laffont (1981). They argue that prices are determined at the beginning of each period at the market-clearing level on the assumption that demand and supplies are subject to zero random shocks. This means that effective demands and supplies are replaced for price determination purposes by Walrasian demands and supplies (i.e. the spillover terms disappear). The implication of this assumption is that in determining prices agents expect no disequilibrium; disequilibrium in fact materializes because of random shocks to the underlying functions. This procedure, called anticipatory pricing, has, as noted by Green and Laffont, the flavor of a rational expectations argument. It answers the criticism implicit in the question: "if sellers expected demand to exceed supply more than temporarily, why do they not raise prices?" In fact, in the Green and Laffont model that is exactly what they do, eliminating disequilibrium on the average.[7]

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6. Even in predicting the actual employment col. 5 is only marginally better: the value of $(\hat{Q}_t - Q_t)^2/T$ is 6.03 for col. 5 and 6.77 for col. 1

7. We are not doing justice to the full argument of Green and Laffont. They also integrate inventories into their model and provide a new test of the hypothesis that equilibrium rather than disequilibrium obtains.

Various unexplored extensions may be suggested by this approach. A simple on recognizes that price in any period are dependent upon expected price, lagged price, as well as excess demand pressures. We may then write

$$p_t = \lambda_1 p_t^e + \lambda_2 (D_t - S_t) + \lambda_3 p_{t-1} + u_{3t} \tag{3-11}$$

In a rational expectations framework $E(p_t) = p_t^e$. Combining (3-11) with (2-1) and (2-2) yields

$$E(p_t) = \lambda_2 \beta_1' x_{1t} - \lambda_2 \beta_2' x_{2t} + \lambda_1 p_t^e + \lambda_3 E(p_{t-1})$$

and thus

$$p_t^e = \frac{1}{1 - \lambda_1} \left[\lambda_2 \beta_1' x_{1t} - \lambda_2 \beta_2' x_{2t} \right] + \frac{\lambda_3}{1 - \lambda_1} \left[\frac{1}{1 - \lambda_1} \left[\lambda_2 \beta_1' x_{1t-1} - \lambda_2 \beta_2' x_{2t-1} \right] + \frac{\lambda_3}{1 - \lambda_1} \left[\cdot \cdot \cdot \right] \right] \tag{3-12}$$

which, when substituted in (3-11), may yield richer dynamic possibilities than previous formulations.

Adjustment in Centrally Planned Economies. As a first approximation, let it be assumed that prices are fully rigid in centrally planned economies.[8] The burden of adjustment is then carried by planned output. The question of how one may model disequilibrium in such cases has been investigated by Charemza and Quandt (1982).

Denote by $Q^*_{t,t-1}$ the output plan for period t made in period $t-1$.

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8. This is clearly just an approximation, made to simplify the analysis. See, for example, Welfe, W. (1981).

There are numerous ways in which plan adjustment might be formulated; we shall briefly note here only some simple varieties. Since writing down a plan adjustment equation is tantamount to modelling the behavior of the planning authorities, there is no way of saying in the absence of empirical tests which is <u>the</u> correct way.

One may hypothesize that the plan is adjusted in response to excess demand pressures; then

$$Q^*_{t+1,t} = Q^*_{t,t-1} + \lambda(D_t - S_t) + u_{4t} \tag{3-13}$$

It is also plausible to suppose then that plan levels also affect demand and supply: Equs. (2-1) and (2-2) would have to be modified by adding to them terms $\phi_1 Q^*_{t,t-1}$ and $\phi_2 Q^*_{t,t-1}$ respectively. These terms express the direct influence that announced plans may have on demand and supply (see Charemza and Quandt (1982) for more details). There are several alternatives that one might consider

$$Q^*_{t+1,t} = (1+\rho)Q^*_{t,t-1} + \lambda(D_t - S_t) + u_{4t} \tag{3-13a}$$

if there is an autonomous growth of 100ρ percent built into the planning process, or

$$Q^*_{t,t-1} = (1+\rho)Q_{t-1} + \lambda(D_t - S_t) + u_{4t} \tag{3-13b}$$

if the baseline for planning is the previous level of actual output achieved. Plan adjustment equations may be employed without any price adjustment or may be employed jointly with a conventional plan adjustment equation. In the latter case the full model consists of (2-1) to (2-4) and (3-13) (or one of its variants. To my knowledge no such model has been actually estimated yet. It seems likely that estimation of such models would add substantially to our understanding of planning processes, as well as provide further insight into the nature of the dynamics of the system.

4. Equilibrium and Disequilibrium

A final issue that we shall consider in some detail is the relationship between states of equilibrium and states of disequilibrium in a model. One aspect of this question is how one might go about testing the null hypothesis that a set of data was generated by an equilibrium specification versus the alternative that it came from a disequilibrium specification. A variety of authors (Quandt (1978b), Hwang (1980), Upcher (1980), Gourieroux, Laffont, Monfort (1980c) and others) has dealt with this question and we shall pursue it no further here.

A different aspect of the question arises from noting that a disequilibrium model (say, given by (2-1) to (2-4)) can almost never produce equilibrium values of the endogenous variables; that is, there is a zero probability that observed p_t, Q_t variables would satisfy the equations of the equilibrium model

$$Q_t = \alpha_1 p_t + \beta_1' x_{1t} + u_{1t} \quad (4\text{-}1)$$

$$Q_t = \alpha_2 p_t + \beta_2' x_{2t} + u_{2t} \quad (4\text{-}2)$$

There is something implausible about this. One might think that under "normal" circumstances there are no impediments to prices fulfilling their market-clearing roles, whereas at other times various constraints may prevent them from doing so. A model that accommodates such a phenomenon would have to be able to switch back and forth between the two states. A simple way to accomplish this might be to specify a 2-state Markov process. This is not likely to be very satisfactory. Although one might "explain" the transition probabilities of the system on the basis of economic factors, such a model can provide no explanation of why, at any particular time, the system switches from one state to another.

A possible approach is to think of the system "choosing" the regime it will obey for data generation purposes so as to minimize certain adjustment costs. This would be completely analogous to the adjustment-cost-minimization justification of the price adjustment equation that was discussed in Section 3. It has the further advantage of providing an endogenous switching mechanism which has inherent in it a new view of dynamics.

Define p_t^* as the price determined by the equilibrium system (4-1) and (4-2) and define p_t^{**} as the solution value for p_t from the system (2-1) to (2-4). Assume that price change from period to period imposes real costs on the system as a whole, due to agents having to adjust their consumption and production plans. The system may then be hypothesized to choose between equilibrium and disequilibrium on the basis of the following scheme:

Choose the equilibrium model if $|p_{t-1} - p_t^*| < |k_1(p_{t-1}-p_t^{**}) + k_2|$

(4-3)

Choose the disequilibrium model otherwise

where $k_1(\geqq 0)$ and k_2 are parameters to be determined. The likelihood function for this model is easily derived (Quandt (1980)).

Let $f(Q_t, p_t|M)$ be the joint pdf of the observable random variables conditional on the model selected where M = (E(quilibrium), D(isequilibrium)).

We need the values of $\Pr\{E\}$ and $\Pr\{D\} = 1 - \Pr\{E\}$. The criteria for model selection are

$$|p_{t-1} - p_t^*| = \left| p_{t-1} - \frac{1}{\Delta_1}\left[\beta_1'x_{1t} - \beta_2'x_{2t} + u_{1t} - u_{2t}\right]\right| \qquad (4\text{-}5)$$

and

$$|k_1(p_{t-1}-p_t^{**}) + k_2| = \left|k_1\left(p_{t-1} - \frac{1}{\Delta_2}\left[\gamma(\beta_1'x_{1t}-\beta_2'x_{2t}) + p_{t-1} + \gamma(u_{1t}-u_{2t}) + u_{3t}\right]\right) + k_2\right| \qquad (4\text{-}6)$$

where $\Delta_1 = \alpha_2-\alpha_1$ and $\Delta_2 = 1 + \gamma(\alpha_2-\alpha_1)$. Denote the arguments of the absolute value functions on the right hand sides of (4-5) and (4-6) by v_{1t} and v_{2t} respectively. Conditional on p_{t-1} , v_{1t} and v_{2t} are jointly normally distributed with mean vector

$$\mu_v = \begin{bmatrix} p_{t-1} - \frac{1}{\Delta_1}(\beta_1'x_{1t}-\beta_2'x_{2t}) \\ k_1(p_{t-1} - \frac{1}{\Delta_2}[\gamma(\beta_1'x_{1t}-\beta_1'x_{2t}) + p_{t-1}]) + k_2 \end{bmatrix}$$

and covariance matrix

$$\Sigma_v = \begin{bmatrix} (\sigma_1^2+\sigma_2^2-2\sigma_{12})/\Delta_1^2 & k_1(\gamma(\sigma_1^2+\sigma_2^2-2\sigma_{12}) + \sigma_{13}-\sigma_{23})/\Delta_1\Delta_2 \\ & k_1^2(\gamma^2(\sigma_1^2+\sigma_2^2-2\sigma_{12}) + 2\gamma(\sigma_{13}-\sigma_{23}) + \sigma_3^2)/\Delta_2^2 \end{bmatrix}$$

The probability $\Pr\{|v_{1t}| < |v_{2t}|\}$ is a bivariate integral

$$\Pr\{E\} = \Pr\{|v_{1t}| < |v_{2t}|\} = \int_0^{\infty}\int_{-\infty}^{0} \frac{1}{2\pi|\Sigma_y|^{1/2}} \exp\left\{-\frac{1}{2}\left[(y-\mu_y)'\Sigma_y^{-1}(y-\mu_y)\right]\right\} dy_1 dy_2$$

$$+ \int_{-\infty}^{0}\int_{0}^{\infty} \frac{1}{2\pi|\Sigma_y|^{1/2}} \exp\left\{-\frac{1}{2}\left[(y-\mu_y)'\Sigma_y^{-1}(y-\mu_y)\right]\right\} dy_1 dy_2 \qquad (4\text{-}7)$$

where $\mu_y = A\mu_v$, $\Sigma_y = A\Sigma_v A'$ and where A is the orthogonal matrix $A = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & -1 \\ 1 & 1 \end{bmatrix}$. The integrals in (4-7) are easily evaluated by numerical integration and the likelihood function is

$$L = \sum_{t=1}^{T} g(Q_t, p_t) \qquad (4\text{-}8)$$

This formulation has been applied to the Rosen-Quandt model discussed in Section 3. The estimated coefficients are extremely close to those reported in the first column of Table 1 for the standard formulation. The parameter k_1 is estimated to be .765 with an asymptotic standard error of .049; k_2 is essentially zero and is not statistically significant. This suggests that the system has a small "bias" against equilibrium: if the price changes implied by the two regimes were identical, the system would "choose" the disequilibrium mode.

Finally, it is interesting to examine the implied probabilities of equilibrium, $\Pr\{E\}$, over the period. In no year does this probability exceed .19. There is a strong relationship between the absolute value of unemployment and the probability of equilibrium. Whenever the proportionate excess supply is greater than about .08 or smaller than -.08, the probability of equilibrium is essentially zero. As the absolute value of excess supply falls toward zero, the probability of equilibrium rises nearly monotonically.

Numerous extensions as well as several alternatives may exist. Whether they will provide sensible answers and reasonable insights into economic systems, remains to be explored.

5. Summary

The discussion in the present paper was concentrated upon some of the controversial conceptual and model-formulation aspects of disequilibrium modelling. We intentionally neglected some of the more arcane technical aspects of estimation. Impressive advances have been made in the last five years to solve the technical problems, and although several problems remain, it is safe to say that the technical progress has achieved a great deal and that we are ready to estimate models of considerable complexity. In particular, progress along the technical discussion has been considerable aided by the recognition that disequilibrium models are more or less closely related to switching models, probit and tobit models and, in general, to self-selection models (see, for example, Maddala (1980)).

Progress has been less impressive in resolving some of the conceptual problems of model formulation such as problems of how to model disequilibrium itself or how to model the dynamics. It seems to me that basically two culprits are responsible for this situation. (1) There has not developed a convincing theory to guide the way towards fruitful hypotheses. Unlike the conventional microtheory in which utility maximization for consumers and profit or output maximization for firms provides a satisfactory framework for deriving testable hypotheses, in disequilibrium modelling there is no framework of comparable adequacy. (2) Empirical work is woefully lacking. Many more formulations have been proposed than estimated and very few of the rival hypotheses have been explicity compared, either via concrete economic examples or via Monte Carlo experiments. To my knowledge, for example, nobody has taken a standard disequilibrium formulation and a partial adjustment model and estimated both from the same set of data and compared the results via appropriate nonnested hypothesis testing procedures à la Pesaran and Deaton (1978). The payoff from such work is likely to be large. We must hope that the coming years will see many fruitful empirical applications.

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