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Endogenous Cycles in Competitive Models: An Overview

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Abstract. *It is a common assertion that, in a world with perfect markets and rational expectations, endogenous cycles could only arise under very unrealistic assumptions. This paper offers a short discussion on this claim and a review of the relevant contributions to the literature on deterministic fluctuations in competitive models. It is argued that these types of fluctuations are more easily obtained when agents are assumed to be heterogeneous and when the production side of the economy is considered. The paper also discusses the existence of endogenous cycles in models with financial market imperfections and nonconvex technologies.*

Keywords. Business cycle, Nonlinear dynamics, Growth, Competitive equilibrium, Financial Markets, Externalities

1 Introduction

Business cycles are called endogenous, or deterministic, when they are generated by some internal mechanism of the economy. Essentially, this term is used to distinguish them from more traditional models, where business-cycle fluctuations are generated by exogenous random shocks.

It is a common assertion that when the economy displays endogenous cycles, the market mechanism is not working smoothly. The intuitive argument supporting this view is well known. If, in a perfect competitive market, prices are expected to follow a nonmonotonic path, agents will buy when prices are low and sell when prices are high. Unrestricted intertemporal arbitrage will then eliminate the fluctuations when agents have the same information.

By now we know that this view is wrong. Gale (1973), Benhabib and Day (1982), Grandmont (1985), and Boldrin and Montrucchio (1986) produced the most significant theoretical contributions showing that endogenous cycles are consistent with perfect competitive markets.[2]

The early literature on this subject highlighted two main reasons as to why cycles may persist even when intertemporal arbitrage is allowed. The first reason has to do with short agents' lifespans and high individual time-discount rates, whereas the second points to the existence of a strong income effect in the saving function. Other contributions have shown the importance of multisector technologies, the interaction of capital accumulation and labor supply, and the role of government assets.

[1]The author acknowledges helpful comments from an anonymous referee.
[2]I include under this definition both the case of complete markets with unrestricted agents' participation, and the case of overlapping generations with perfect foresight.

However, there is no general consensus that, in a world with perfect markets and rational expectations, endogenous cycles are a pervasive phenomenon. Most economists are still claiming that the examples proposed by this literature require some extreme assumptions, and that we should confine any example of a deterministic cycle to the set of pathological cases, somewhat at variance with agents' "average" behavior.

This paper is a short essay on how we should assess this claim in light of the recent literature on the subject. Far from being a systematic survey,[3] this paper will review in a nontechnical form a selected number of papers, and try to collect what I consider the main points of a discussion about the compatibility between competitive markets and deterministic cycles. In doing this, I will only concentrate on the two most popular models of the macro literature: the "infinitely lived agent" and the "overlapping generations" models, and abstract completely from extrinsic uncertainty.

In addition, the paper will shortly discuss the existence of deterministic cycles in models with market imperfections.

First, I will review some results based on imperfect financial markets. The most popular form of imperfection assumed in the literature is characterized in terms of liquidity constraints. However, this approach is not completely satisfactory, since it does not try to derive the constraints from more primitive assumptions about agents' information and/or about the underlying market structure. Possible alternative approaches will be discussed.

Finally, I will mention some insights about the existence of endogenous cycles in models with productive externalities and increasing returns, which are now familiar from the recent literature.

2 Pure Exchange or One-Sector Technologies

In this section, I will discuss standard models in pure exchange or with one-sector technologies.

When the model has a representative infinitely lived agent, maximizing a concave, time-separable utility function in consumption only[4] (optimal growth model), deterministic cycles are simply nonexistent.[5]

By the second welfare theorem, the competitive equilibria of this model can be derived from the solution of the following problem:

$$\max \sum_{0}^{\infty} \beta^t u(c_t)$$

subject to:

$$c_t + k_{t+1} \leq f(k_t) + (1-\delta)k_t,$$

$$k_t,\, c_t \geq 0,$$

$$k_0 > 0,$$

$$t = 0, 1, \ldots$$

where c and k represent per-capita consumption and capital, $f(.)$ is a neoclassical production function, $u(.)$ is a concave utility function, β is the time-discount factor, and δ is the depreciation rate.

Using dynamic programming techniques, we can reduce the above problem to the problem of finding the sequence $\{k_t\}$ of capital stocks satisfying the following functional equation:

$$V(k_t) = \max_{k_{t+1}} \{u(f(k_t) - k_{t+1}) + \beta V(k_{t+1})\}$$

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[3] For a complete survey on the subject, see Boldrin and Woodford (1990), Guesnerie and Woodford (1991), or Nishimura and Sorger (1996).

[4] This is the model considered, for example, in the macrotextbook by Blanchard and Fischer (1989).

[5] This statement does not generalize to optimal growth models where the utility function has a different form, as, for example, in Majumdar and Mitra (1994), where the latter includes the capital stock as an additional argument.

where $V(.)$ is the value function.

It is a simple exercise to show that when $f(.)$ and $u(.)$ are increasing and concave, the value function is also increasing and concave.

Since the first-order condition for the above problem is:

$$u'(f(k_t) - k_{t+1}) = \beta V'(k_{t+1}),$$

it follows that when k_t goes up, for a given k_{t+1}, marginal utility falls, and from the above equation, there must also be a fall in $V'(.)$. By concavity, this implies a rise in k_{t+1}. Then, the monotonic relation between present and future capital stocks is a consequence of concavity in the economy with perfect capital markets.

Within the overlapping generations (OG) literature, the situation is very different. Deterministic cycles are more easily obtained, even within simple one-good pure exchange models, as it was first suggested by Gale (1973).

Consider an overlapping generations model with identical generations of two-period-lived agents having stationary endowments. In this model, individuals of generation t face prices p_t and p_{t+1} only. Then, by stationarity, we can write the aggregate saving function in period t as:

$$s(R_t) = w^y - c_t^t \equiv s_t,$$

where $R_t = p_t/p_{t+1}$ is the implicit real interest rate between t and $t+1$, w^y is the young agents' aggregate endowment, and c_t^t is their consumption. Now consider the following two equations defining the $t-1$ generation budget constraint and the t-period market clearing condition, respectively:

$$c_t^{t-1} = w^o + \frac{p_{t-1}}{p_t} s_{t-1},$$
$$c_t^{t-1} = w^o + s_t,$$

where w^o is the old agent's endowment.

Putting the above conditions together, we obtain:

$$s(R_t) = R_{t-1} s(R_{t-1}).$$

It is readily seen that a decreasing saving function is a necessary and sufficient condition for the equilibrium sequence of real interest rates to be nonmonotonic.

However, the assumptions required for proving the existence of robust persistent equilibrium fluctuations have been often disputed. In Grandmont's paper (1985), the interest-rate elasticity of the saving function cannot be higher than $-1/2$ at the stationary state, for a period-two cycle to be possible, and these values are generally considered implausible.

The fact that cycles are more easily obtained in OG models is not surprising. In simple terms, one can say that the extent of intertemporal arbitrage activity is limited by the length of agents' lifespans (i.e., by their market participation). The early literature sounded as a strong confirmation of the above argument. Since the OG models used in this literature have agents living for only two periods, all cycles have a periodicity higher than or equal to the agents' lifespans. This consideration lead Sims (1986) to question the relevance of the literature based on the OG framework. His main argument was that actual business cycles display a very short periodicity (relative to agents' lifespans).

What happens in the OG model when the length of a single time period is arbitrarily short with respect to the agents' lifespan is still an open question. The dynamical system governing the evolution of an OG economy where agents live for a large number of periods is highly dimensional, and a full characterization of the conditions under which cycles may occur is difficult to detect.

An example provided by Aiyagari (1989) shows that the possibility of having endogenous cycles in a pure exchange economy vanishes as the lifespan of agents is long enough with respect to the length of a single time period. However, Reichlin (1992a) shows that this result is critically dependent on the assumption that all agents' endowments are bounded away from zero. Under the alternative assumption that future endowments are not bounded away from zero, Reichlin (1992a) shows that period-two cycles may persist in an OG model where agents are infinitely lived.

In this example, the values of the time-discount rate and the relative degree of risk aversion (a measure of the curvature of the utility function) allowing for the existence of cycles are negatively related. A smaller time-discount rate requires a higher relative degree of risk aversion for cycles to be possible. It is interesting to notice that what matters in these examples is not how long people live, but, rather, what is the structure of their stream of endowments.[6]

Then, we face some sort of contradiction in what has been the leading argument so far. If it is true that cycles may be obtained in the OG model even when agents are infinitely lived, then something more than agents' lifespan is contributing to the cycles.

One may suggest that restricted market participation is the very reason why cycles are more likely in the OG model. In fact, the demographic structure of this model implies that the agents in each generation only trade in the markets that are open when they are alive. However, as noted by Shell (1971), the OG model is formally equivalent to a complete market Arrow-Debreu economy where agents derive utility from, and have endowments over, a subset of the existing goods. Then, restricted market participation does not seem to be crucial. In my view, what really matters is that, contrary to the standard optimal growth model, the OG framework is characterized by agents' heterogeneity, which is at least a consequence of the demographic structure of the model.

3 Labor Supply and Negative Assets

"Pathological" behavior of agents' preferences is not always necessary to generate deterministic cycles within the OG model.

Two examples show that cycles may exist under standard assumptions about saving behavior (low-income effect). Both of these examples show the existence of a Hopf bifurcation for the (discrete-time) dynamical system generated by the model. The bifurcation is shown to give rise to a stable or unstable closed curve around the stationary state.

The first of these examples is due to Farmer (1986). He showed that cycles are possible when the government is a net creditor with respect to the private sector. The argument is very simple. Suppose that the capital stock is initially low, and thus the marginal productivity of capital is relatively high. This implies a high interest rate. If this rate is higher than the growth rate of the population, then, with a constant flow of taxes and public spending, the stock of the government net assets is growing. Eventually, the capital stock overcomes the level at which the net marginal product of capital (and the interest rate) is just equal to the rate of population growth. Then, the value of the government net assets starts falling. Due to reduced private indebtedness, private investment in newly produced capital goods will also start falling, and the marginal product of capital may get back to a level at which the interest rate is higher than the population growth rate.

This example has the advantage of finding the source of deterministic fluctuations outside the set of assumptions defining agents' preferences and technology. The net asset position of the government is a variable that, in principle, cannot be disputed (even though, in practice, there may be problems in interpreting the available statistics). On the other hand, a situation in which the private sector is a net debtor with respect to the government is somewhat atypical.

[6] Incidentally, one can observe that the same consideration applies with respect to the efficiency of equilibria in the overlapping generations model.

The second example is due to Reichlin (1986). Here the crucial role in generating endogenous cycles is played by the elasticity of the labor supply with respect to the wage and interest rate. In a model with a neoclassical technology, these two variables are negatively correlated. On the other hand, with standard preferences, they both have a positive effect on saving. Now assume that the incentive to work is primarily due to a desire to save to increase future consumption, and consider a dynamic path where the wage rate as well as the capital stock are rising.

Along this path, saving is increasing, and due to the rise of the wage rate, the interest rate is falling. As the interest rate falls, eventually the relative price of future consumption in terms of leisure will become so high as to depress saving and capital accumulation. With a diminishing capital stock, the interest rate will start rising, stimulating saving and capital accumulation again.

This mechanism relies on the condition that capital and labor have a low degree of substitutability, otherwise a rising wage rate would strongly decrease the labor-capital ratio, leaving little chances for rising savings and a growing capital stock. In a recent paper, Grandmont, Pintus, and de Vilder (1995) evaluated that, for reasonable values of other parameters, the elasticity of substitution between capital and labor cannot exceed 3% for cycles to be possible.

4 The Importance of the Technology

The example in Reichlin (1986) shows that technology may play an autonomous important role in generating deterministic cycles. As I mentioned in the previous section, combining an elastic labor supply and a low substitutability between capital and labor may induce the existence of cycles in a simple overlapping generations model under standard assumptions about agents' preferences.

Multisector technologies can play an autonomous role in generating cycles independently of the effect of labor supply. This is not only true in overlapping generations models [see Reichlin (1992b) and Galor (1994)], but also in the optimal growth literature. Early contributions in this subject are due to Benhabib and Nishimura (1979, 1985).

The intuition for the existence of endogenous cycles in a two-sector economy is well explained in Benhabib and Nishimura (1985). Consider an economy with a consumption and a capital sector, and let $c = T(k, y)$ be the production possibility frontier (PPF). Here c stands for consumption, k for capital stock, and y for investment. For simplicity, assume full capital depreciation. Then, at time t, we can set $k = k_t$ and $y = k_{t+1}$. An oscillating trajectory is such that:

$$k_t < y_t = k_{t+1} > y_{t+1} = k_{t+2}.$$

This possibility may arise when the consumption sector is more capital intensive. In fact, to induce the oscillation, we need an increase of the capital stock from k_t to $k_{t+1} > k_t$ (a shift outward of the PPF) to generate a fall of the investment output from y_t to $y_{t+1} < y_t$ and a rise of consumption from c_t to $c_{t+1} > c_t$.

Under the Rybczynski theorem, this can happen if the consumption sector is more capital intensive than the investment sector. Formally, under this assumption the theorem implies:

$$\partial c/\partial k > c/k,$$

$$\partial y/\partial k < 0.$$

Using this type of model, Benhabib and Nishimura (1985) prove the existence of period-two cycles in the optimal growth model.

It is commonly argued that deterministic cycles can only occur in optimal growth models when the representative agent is very impatient. Accordingly, the time-discount rate is viewed as the critical parameter in these models. This view comes from the turnpike theorem [see Scheinkman (1976)], according to which the dynamics of the capital stock is monotonic near the stationary state when the time-discount rate is sufficiently low.

However, the turnpike theorem does not imply that a high time-discount rate is necessarily a critical condition for the existence of cycles. Within a three-sector economy, Benhabib and Rustichini (1990) show that, for all time-discount rates, there exists a Cobb-Douglas technology such that the associated optimal growth model generates deterministic cycles.

Clearly, a more complicated situation arises when we check for the possibility of chaotic dynamics [see Sorger (1992) and Montrucchio and Sorger (1996) for an analysis of the relation between the time-discount rate and the complexity of optimal solutions]. The "anti-turnpike" theorem due to Boldrin and Montrucchio (1986) tells us that any dynamic behavior of a sequence of capital stocks is compatible with a standard optimal growth model with a multiple-sector technology. However, whether chaotic dynamics is a "plausible" phenomenon in the multisector growth model is still an open question.

Most of the examples derived so far show that this type of dynamics can only occur for very high time-discount rates. Within a standard two-sector growth model with a smooth neoclassical technology, Boldrin (1989) shows that chaos is only possible if, in addition to a high time discount, the technology allows for factor-intensity reversal. The only contributions that are at variance with these examples are the ones by Nishimura, Sorger, and Yano (1994) and Nishimura and Yano (1995). They show that the discount rate compatible with chaos in a standard two-sector growth model can be arbitrarily low when the technology is assumed to be Leontiev and corner solutions are allowed.

Thus, the possibility of endogenous fluctuations with perfect markets and perfect foresight cannot be disputed, and it seems to be arising from a variety of different assumptions, the most relevant of which are agents' high degree of impatience, strong income effects, and low substitutability between capital and labor in the technology. However, the question whether the nature of these assumptions and the predictions of these models could be reconciled with estimated parameter values and actual business-cycle phenomena is still open.

Those who have strong doubts about the relevance of these models have turned to the study of endogenous cycles in models containing some form of market failure. In the next two sections I will give a brief account of a set of models based on the imperfect functioning of the financial system and on the existence of increasing returns.

5 Imperfect Financial Markets

It is a natural conjecture that, in some cases, market imperfections limiting agents' intertemporal arbitrage may give rise to the possibility of endogenous fluctuations. By now, there is a rather large literature on this subject; a pioneering work is by Bewley (1986).

To isolate the effect of market imperfections from other sources of business fluctuations (such as agents' impatience, short lifespans, and strong income effects), most of this literature has focused on the infinitely lived agents' model, and tried to abstract from any assumption about the size of the time-discount rate.

Becker and Foias (1987) and Woodford (1986, 1989) show that a market imperfection that generates cycles can take the very simple form of a constraint on the level of individual indebtedness in a model with heterogeneous infinitely lived agents. In these models, it is crucial that some set of agents are more impatient than the remaining set of the population. We know from the work of Becker (1980) and Becker and Foias (1987) that in this case, the less impatient agent will end up consuming the entire amount of the available resources. If there is a borrowing constraint, we easily get equilibria where this agent owns the entire stock of capital and all remaining agents (the more impatient) have zero or negative assets.

This kind of consumer's heterogeneity can be responsible for the emergence of endogenous cycles even in the simple one-dimensional optimal growth model. The intuition can be readily explained with the help of the following illustration.

Consider a standard one-sector infinitely lived agents' model with two consumers, A and B. Consumer B is more impatient than A, and he cannot borrow in the capital market. For simplicity, assume also that agent A has no labor endowment, agent B has no initial capital, and that the borrowing constraint for agent B is binding in all periods. Then, the resource constraint and agent's B budget equation are:

$$c_t^A + c_t^B + k_{t+1} = f(k_t), \text{ and}$$

$$c_t^B = w_t = f(k_t) - k_t f'(k_t),$$

where w is the wage rate.

From these equations it follows that in equilibrium, we have:

$$c_t^A = k_t f'(k_t) - k_{t+1}.$$

The first-order condition for agent A's capital accumulation to be optimal is:

$$u'(k_t f'(k_t) - k_{t+1}) = \beta V'(k_{t+1}),$$

where β, $u(.)$, and $V(.)$ are the time-discount rate, the utility function, and the value function of agent A.

This equation shows that concavity is not enough to prove the monotonicity of the relation between present and future capital stock. If:

$$\partial(kf'(k))/\partial k = f'(k) + kf''(k) < 0,$$

then a rise in k_t implies a fall in k_{t+1}.

Here again, as in the overlapping generations model, the heterogeneity of agents plays a fundamental role in generating cycles.

There is some "ad hoc" feature in the models with borrowing constraints. In particular, these constraints are not derived from more primitive assumptions. A more interesting line of research in the theoretical literature has focused on financial market imperfections deriving from market incompleteness, uncertainty, and asymmetric information between borrowers and lenders. Some important examples in this literature include Bernanke and Gertler (1989), Greenwald and Stiglitz (1993), and Kiyotaki and Moore (1995).

These models explain business-cycle fluctuations through various forms of borrowing constraints deriving from incomplete insurance opportunities, the emergence of second-best contracts satisfying a set of incentive constraints, and the cyclical behavior of agency costs arising from intermediation. Gertler (1988) provides an overview of most of these models.

With some notable exceptions [such as Greenwald and Stiglitz (1993)], however, these models are more suitable for analyzing the persistence of aggregate shocks and their propagation mechanism, rather then offering a support for the existence of truly endogenous fluctuations. Some additional work needs to be done to provide the theory of endogenous cycles based on financial market imperfections with more solid microeconomic foundations.

In Greenwald and Stiglitz (1993), endogenous cycles derive from the effect of the firms' net asset position on bankruptcy risk. In particular, when output is rising, the following rise in wages and interest rates imply a fall of firms' internal funds. This will reduce equity levels and raise bankruptcy costs, leading eventually to a reduction in output.

An alternative approach within this line of research is proposed in a paper by De Nicolò, Reichlin, and Siconolfi (1996), where business-cycle fluctuations are based on the interplay of a moral hazard and an adverse selection problem. In this case, cycles are not created by liquidity constraints or collateral requirements, but they emerge from a change in the distribution of investment projects (differentiated by the degree of risk and productivity). Using a very simple model where identical entrepreneurs face different technologies to produce a single capital good and financial intermediaries are unable to observe the borrowers' technological choices, we characterize the "type" of incentive-compatible contracts arising in a competitive equilibrium as a function of the amount of loanable funds. In our setting, there is a sort of "cleansing effect of recessions," comparable to the one documented by Caballero and Hammour (1994). In particular, during the upswing of the cycle (large amount of loanable funds), competitive lenders devise pooling contracts whereby all projects get financed at the same interest rate and a large proportion of "bad" projects are induced. During the downturn, on the other hand, lenders tend to be selective, offering separating contracts whereby bad projects can only be financed at high interest rates. The evolution of this type of contracts as a function of the amount of loanable funds is the very reason why cycles may be endogenous and persistent in our model. In fact, during the upturn of the cycle, an increasing proportion of bad projects implies a loss of aggregate resources, and this may eventually give rise to a fall in the amount of loanable funds, i.e., to a recession. In turn, the recession, by inducing financial intermediaries to choose separating contracts, will eventually improve the average quality of investment projects and set the stage for a recovery.

6 Externalities

New insights on the emergence of endogenous cycles have been derived from the revived interest in the aggregate effects of local productive externalities and increasing returns arising from cumulative knowledge and human capital, which was initiated by the endogenous growth literature [see Romer (1986) and Lucas (1988)].

We have seen that a basic condition for the absence of endogenous cycles in the "standard" one-sector growth model is the concavity of the technology. The latter is also crucial for the emergence of monotonic equilibrium paths in the OG model, when goods are gross substitutes. Thus it is not surprising that with convex technologies, endogenous cycles may be possible. Assuming externalities in production is a way to justify these technologies and to reconcile increasing returns with standard analytical methods of general equilibrium theory.

Some examples of this approach are Hammour (1988), Boldrin and Rustichini (1991, 1994), Boldrin (1992), Benhabib and Farmer (1994), Benhabib and Perli (1994), and Azariadis and Reichlin (1996). Although some of these models are more focused on the issue of indeterminacy of equilibria, they also provide existence results for endogenous cycles as a by-product.

In the work of Hammour (1988), Boldrin and Rustichini (1991), Boldrin (1992), and Azariadis and Reichlin (1996), endogenous cycles are possible because the technology is sufficiently convex to make the marginal product of capital increasing in the capital stock. Boldrin (1992) and Azariadis and Reichlin (1996) analyze OG models where individuals' saving is a nondecreasing function of the interest rate. In Azariadis and Reichlin, the cycles are associated with a crowding-out effect. In particular, in the upswing of the cycle, capital stock grows along with the interest rate (the marginal product of capital). In turn, a high interest rate sets the stage for a fast growth of the stock of public debt. The latter crowds out investment, lowers capital, and eventually reverses the interest-rate movement.

In Benhabib and Farmer (1994), the existence of endogenous cycles is based on the assumption that increasing returns are sufficiently strong to make labor demand an increasing function of the amount of employment. Then, a growing capital stock, by shifting the labor demand curve up, will lower employment and wages. However, a growing capital stock goes along with an increasing consumption, which will tend to increase employment and wages.

Boldrin and Rustichini (1994) and Benhabib and Perli (1994) analyze models with externalities and a two-sector technology when the private return to capital is nonincreasing in the capital stock. Whereas we know already that a two-sector technology may be responsible for the existence of cycles, the role of the externality is to make these cycles compatible with "realistic" values of the time-discount rate. Benhabib and Perli (1994) make clear that the externalities compatible with cycles (and indeterminacy) and low discounting need not be too large when labor supply is endogenous.

7 Conclusions

The literature on equilibrium deterministic cycles in models where agents have perfect foresight and rational behavior has shown that persistent business-cycle fluctuations can be a pervasive phenomenon.

The importance of these results goes beyond the opportunity of describing real-life phenomena and explaining why they may occur. More theoretical problems are now disclosed, concerning the relation between learning and predictions and the relation between social welfare and cycles.

As for the first problem, I just want to mention two questions about which there is already a large and growing literature.

1. The difficulty of basing the perfect foresight assumption on a rational learning mechanism when the variables to be anticipated have a complicated deterministic dynamics, and

2. that deterministic cycles are often coming along with the indeterminacy of equilibria and the existence of sunspot phenomena. Again, this may question the relevance of the perfect foresight assumption, even when we have stationary environments and rational agents.

The second problem arises from the following simple questions. If deterministic cycles are generated from the solution of a Social Planner, as in the optimal growth literature with perfect markets, why should we think of them as a disturbing phenomenon? Is there a role for a stabilization policy? Is it true that we should mainly be interested in endogenous cycles that are incompatible with Pareto optimality?

If, on the basis of these questions, there are reasons to be interested only in "nonoptimal" endogenous fluctuations, then we should concentrate on OG models (where the first welfare theorem often fails), on models with financial market imperfections or models with externalities and imperfect competition.

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Editorial Policy

The *SNDE* is formed in recognition that advances in statistics and dynamical systems theory may increase our understanding of economic and financial markets. The journal will seek both theoretical and applied papers that characterize and motivate nonlinear phenomena. Researchers will be encouraged to assist replication of empirical results by providing copies of data and programs online. Algorithms and rapid communications will also be published.

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