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Miscellany

Some Unfamiliar Dynamics of a Familiar Macro Model
A Note

By

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The idea that for small disturbances the full employment equilibrium is stable while for large disturbances it is unstable was coined by Leijonhufvud in the notion of a "corridor." We discuss the existence of a corridor in the standard Keynesian–monetarist textbook macro-model. It turns out that though the full employment steady state of this model may be locally stable — which is the case when the well-known Cagan condition holds — the model is never globally stable. This is due to the inherent non-linearity in the demand for money function, arising from non-negativity of the nominal rate of interest. Thus, perhaps surprisingly, the Cagan condition is both necessary and sufficient for the existence of a corridor in the Keynesian–monetarist model.

1. Introduction

This note is concerned with an unfamiliar implication of a familiar macrodynamic model. It is shown that the full employment equilibrium of the simple Keynesian–monetarist medium-run model has to be unstable in the large, whether it is locally stable or not. By Keynesian–monetarist medium-run model we mean the IS-LM model dynamized

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by adding the expectations-augmented natural rate Phillips curve and adaptive expectations. The qualifier "simple" signifies that the consumption function is of the simple Keynesian type having current income as the only argument. It is well-known that, depending on the parameters, the steady state of this model may be locally stable or unstable (Tobin, 1975; Scarth, 1977; Taylor, 1977; Yarrow, 1977). The stability hinges on the celebrated condition found by Cagan in his classical study of hyperinflation (Cagan, 1956).

Tobin (1975) hinted at the possibility that the dynamics might give rise to stability for small disturbances, but instability for larger shocks. Tobin did not, however, analyze the problem in a rigorous way and left the definite conclusion for further investigation.

Using the geometry of the phase plane we show that Tobin's conjecture is confirmed when the inherent non-linearity in the demand for money function, arising from non-negativity of the nominal rate of interest, is taken into account. Large contractionary disturbances lead to a *dynamic* liquidity trap so that the system never returns to the steady state. Hence, in the simple Keynesian–monetarist model deep slumps are self-sustaining. In case the Cagan condition holds, i.e., the steady state is *locally* stable, this implies the existence of a "corridor," a notion introduced by Leijonhufvud (1973). A corridor is the limited neighborhood of stability around a steady state which is locally stable but not globally stable. Conditions for the existence of a corridor in different models are discussed in Grossman (1974), Howitt (1978), Löfgren (1979), Siven (1981), Raymon (1981), Balasko and Royer (1985), and van de Klundert and van Schaik (1990). The question of the existence of a corridor in the Keynesian–monetarist model was briefly considered in Cugno and Montrucchio (1984). They approached the problem by means of the Hopf bifurcation theorem. This provided no concise condition as to the existence of a corridor. We show, however, the global result that the Cagan condition is both a necessary and a sufficient condition for the existence of a corridor.

Although the model we consider is very simplistic (and degenerates if expectations are rational instead of adaptive) it *is* one of the core models of intermediate macroeconomic textbooks and of discussions of economic policy in the press and among policy makers (cf. Mankiw, 1990; Tobin, 1993). The fact that the model is necessarily unstable in the large therefore seems worthy of some attention.

2. Keynesian–monetarist Dynamics

The model is the standard imperfectly flexible prices version of the IS-LM model. The symbols are: P price of output, M nominal money supply (equal to monetary base), $m = M/P$ real money supply, y real output, $\dot{P}/P$ actual rate of inflation, x expected rate of inflation, i nominal rate of interest, r real rate of interest. The model consists of the following six equations, Eqs. (3) and (4) being merely identities.

$$y = C(y) + I(y, r), \quad 0 < C_y < C_y + I_y < 1, \ I_r < 0 , \tag{1}$$

$$m = L(y, i), \quad L_y > 0, \ L_i < 0 , \tag{2}$$

$$r = i - x , \tag{3}$$

$$m = \frac{M}{P} , \tag{4}$$

$$\frac{\dot{P}}{P} = \varphi(y) + x, \quad \varphi(y^*) = 0, \ \varphi' > 0 , \tag{5}$$

$$\dot{x} = b\Big(\frac{\dot{P}}{P} - x\Big) . \tag{6}$$

The behavioral functions C, I, and L (i.e., consumption, investment, and money demand), and the Phillips curve φ are continuously differentiable. M, y^*, and b are positive constants. y^* is the "natural" rate of output defined as that level of output which is consistent with a constant rate of inflation. We may also speak of y^* as "full employment output" meaning by this no more than the non-accelerating-inflation level of output. Given the initial values $x(0)$ and $P(0)$ the model generates time paths of the six endogenous variables: y, m, x, i, r, and P.

The short run

In the short run, i.e., for fixed t, there are a historically given money supply, a given output price, and given inflation expectations. Therefore, when considering the LM equation (2) and the IS equation,

$$y = C(y) + I(y, i - x) , \tag{7}$$

derived from (1) and (3), m and x are given for fixed t. The "IS curve" is downward sloping and the "LM curve" upward sloping. The short-run solution (y, i) is therefore unique, and we can write y and i as continuously differentiable functions of x and m:

$$y = f(x, m), \quad i = g(x, m) \ , \tag{8}$$

to be characterized later. The question of *existence* of this solution (y, i) to (2) and (7) calls for a comment since a study of global dynamics should take account of a large range of variation of x and m. We assume the following boundary conditions:

A1. *(i)* $C(0) > 0$, and
(ii) there exists β, $0 < \beta < 1$, such that $C_y + I_y \leq \beta$ everywhere.

A2. For all $y > 0$:
(i) $\lim_{i \to 0} L(y, i) = \infty$, and
(ii) $\lim_{i \to \infty} L(y, i) = 0$.

Part *(ii)* of A1, i.e., that the marginal propensity to spend is always bounded away from one, strengthens the standard condition $0 < C_y + I_y < 1$ in an economically unimportant, but technically convenient way. As for A2 its rationale is: when the rate of interest approaches zero, everyone wants to hold his wealth in the form of cash and may indeed want to borrow and keep the proceeds in cash. This is because some interest reward is needed to compensate for the lower degree of liquidity which characterizes bonds and equities. On the other hand, at very high rates of interest nobody willingly holds money, and society tends to some other means of exchange.[1]

In view of A2 and $L_i < 0$, we can in principle solve (2) with respect to i, for given $y > 0$, $m > 0$. This gives

$$i = h(y, m) > 0 \quad \text{with } h_y = -\frac{L_y}{L_i} > 0, \ h_m = \frac{1}{L_i} < 0, \quad \text{and} \tag{9}$$

$$\text{for all } y > 0, \ \lim_{m \to \infty} h(y, m) = 0, \ \lim_{m \to 0} h(y, m) = \infty \tag{10}$$

by A2. Inserting (9) in (7), it is straightforward to show:

Property 1: Assume A1 and A2. Then given any x and m, where $m > 0$, the system (2) and (7) has a unique solution (y, i), as indicated in (8), and y and i are positive.

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[1] An example of a demand for money function obeying A2 is the case of constant interest elasticity: $L(y, i) = \psi(y) i^{-\epsilon}$, $\psi' > 0$, $\epsilon > 0$.

For use later we observe that

$$\frac{\partial y}{\partial x} = f_x = \frac{-I_r}{1 - C_y - I_y + I_r L_y / L_i} > 0 \, ,$$
$$\frac{\partial y}{\partial m} = f_m = \frac{I_r / L_i}{1 - C_y - I_y + I_r L_y / L_i} > 0 \, . \tag{11}$$

Dynamics

From (5), (6), and (8) we obtain

$$\dot{x} = b\varphi(f(x, m)) \, . \tag{12}$$

Combining (4), (5), and (8) gives

$$\dot{m} = -[x + \varphi(f(x, m))]m \, . \tag{13}$$

In view of Property 1 the dynamic system (12)–(13) is defined for all (x, m), $m > 0$. The domain of definition of the system will be called U, that is $U = \mathbb{R} \times \mathbb{R}_{++}$.

A *steady state* is a time path along which x and m, and therefore y and i, are constant. The steady state values of x and m are called x^* and m^*, respectively. Now, $\dot{x} = 0$ implies, by (12) and (5), that output equals y^*, the natural rate of output. Then, by (13), $\dot{m} = 0$ implies $x^* = 0$. Furthermore, m^* is the positive solution in m to the equation $y^* = C(y^*) + I(y^*, h(y^*, m))$ which is derived by inserting (9), $y = y^*$, and $x = 0$ into (7). To ensure existence of such a solution we need sufficient variability of investment demand. We shall assume

A3. $C(y^*) + I(y^*, \infty) < y^* < C(y^*) + I(y^*, 0)$.

I.e., at a low (high) real rate of interest investment is (is not) sufficient to absorb full employment savings. Now follows:

Property 2: Given A1, A2, and A3, the dynamic system (12)–(13) has a unique steady state (x^*, m^*) in its domain of definition, U, and $x^* = 0$. Like x^*, m^* is independent of b, the speed of adjustment of inflation expectations, and of φ', the steepness of the short-run Phillips curve.

Investigating the Jacobian of (12)–(13), evaluated at the steady state, we find that the determinant is $b\varphi' f_m > 0$ and the trace is $\varphi'(bf_x - f_m m)$. Thus, the steady state $(0, m^*)$ is *locally asymptotically stable* — i.e., a *sink* — if $bf_x(0, m^*) < f_m(0, m^*)m^*$. By (11), this inequality is equivalent to

$$-b\frac{L_i^*}{m^*} < 1 . \tag{14}$$

The steady state is *unstable*[2] if this inequality is reversed.[3] This is a manifestation of the ambiguous role of price dynamics in relation to stability. While falling prices increase real money balances, thereby lowering the nominal rate of interest, i, and tending to pull $i - x$ downwards, the *expectation* of falling prices evidently works in exactly the opposite direction, tending to increase $i - x$.[4] The first mentioned force is the stronger one when the sensitivity of the nominal rate of interest with respect to the money supply, $-m^*/L_i^*$, is high, i.e., when $-L_i^*/m^*$ (the semi-elasticity of money demand with respect to the nominal rate of interest) is low.

The stability condition (14) is called the *Cagan condition* because it is formally identical to the stability condition found by Cagan (1956) in his classical analysis of the purely monetary dynamics in situations of hyperinflation. As to the Keynesian–monetarist model the condition (14) was, in essentially the same form, discovered by Tobin (1975). The condition is mentioned in Dornbusch and Fischer (1981, p. 444), but — strangely enough — not explicitly in later editions, and in Scarth (1988, p. 60).[5]

3. The Corridor

Leaving the merely local stability analysis we turn to global dynamics. Tobin (1975, p. 201) gave some hints that the stabilizing force, the

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[2] A steady state which is not locally stable is called *unstable*. Our definitions are as in Hirsch and Smale (1974).

[3] While φ', i.e., the sensitivity of (unanticipated) inflation with respect to the activity level in the economy, influences neither the position of the steady state nor the question of asymptotic stability, it turns out that oscillations are less likely to occur, the larger is φ'.

[4] This point was already stressed by Keynes (1936, p. 263).

[5] For some extensions, see Groth (1988). From another perspective the relation between price flexibility and stability is discussed in De Long and Summers (1986) and King (1988). They deal with stability in the sense of lack of statistical variance of output rather than as convergence. See also Chap. 4 in Sheffrin (1989).

Keynes effect, tends to be relatively weaker the further below equilibrium output of the system is. We shall prove this conjecture, i.e., that the simple Keynesian–monetarist model is necessarily unstable for large contractionary disturbances. Deep slumps are not self-correcting. This implies that *if* (14) holds, i.e., the steady state is *locally* stable, then there exists what Leijonhufvud (1973) calls a "corridor."

To be more precise we introduce the following definitions. Remember that the domain of definition, $\mathbb{R} \times \mathbb{R}_{++}$, of our dynamic system (12)–(13) is called U. The steady state (x^*, m^*) of the system (12)–(13) is called *globally asymptotically stable* if every solution $(x(t), m(t))$ with $(x(0), m(0))$ in U converges to (x^*, m^*) for $t \to +\infty$. A neighborhood N of (x^*, m^*) in U is called a *neighborhood of asymptotic stability* if any solution starting in N converges to (x^*, m^*) for $t \to +\infty$. Given a steady state which is locally asymptotically stable but not globally asymptotically stable, the union of all its neighborhoods of asymptotic stability is called a *corridor*.[6]

By using the strict notion of asymptotic stability as a criterion we diverge from Howitt who found this notion inappropriate. He argued that "for the concept of asymptotic stability corridor-effects seem unlikely to occur" (Howitt, 1978, p. 268). We do not agree since in reality non-linearities of some kind are always present and may cause a system which is locally asymptotically stable to be unstable in the large.

In the present case it is the non-linearity in the demand for real balances that is important. This non-linearity follows from the fact that zero is an absolute floor to the nominal rate of interest (as expressed in A2). Whatever the value of the interest elasticity, increases in real money supply become less and less effective in reducing the nominal rate of interest. To see the implication of this we draw the phase portrait of the system (12)–(13) (cf. Fig. 1). The slopes of the $\dot{x} = 0$ and $\dot{m} = 0$ loci are given by

$$\left.\frac{\mathrm{d}m}{\mathrm{d}x}\right|_{\dot{x}=0} = -\frac{f_x}{f_m}, \quad \left.\frac{\mathrm{d}m}{\mathrm{d}x}\right|_{\dot{m}=0} = -\frac{f_x}{f_m} - \frac{1}{\varphi' f_m} .$$

At the point of intersection the slope of the $\dot{m} = 0$ locus is therefore smaller than the slope of the $\dot{x} = 0$ locus. Observe that above the $\dot{x} = 0$ locus we have $y > y^*$ and below the $\dot{x} = 0$ locus $y < y^*$. Moving north-east in the diagram is associated with rising output.

[6] A corridor is thus a *basin* (Hirsch and Smale, 1974, p. 190) which does not contain the whole of $U \setminus \{(x^*, m^*)\}$. The intuitive meaning of the term "corridor" is perhaps clearest if we think of the economy in (x, m, t)-space rather than in (x, m)-space.

Now, whatever the specific shape of the demand for money function, as long as A2 *(i)* holds, the $\dot{x} = 0$ locus in the phase diagram tends to become vertical as x declines towards some critical value. Indeed, along the $\dot{x} = 0$ locus, $y = y^*$ and therefore, by (1), the real rate of interest, r, has a constant value, the steady state value $r^* = h(y^*, m^*)$. Thus, along the $\dot{x} = 0$ locus we have $i = r^* + x = h(y^*, m)$, by (2) and (9). Hence, as x tends to $-r^*$ along the $\dot{x} = 0$ locus, $h(y^*, m)$ tends to zero and m tends to $+\infty$, by (10), as shown in Fig. 1. This is a manifestation of the non-negativity of the nominal rate of interest, and instability in the large follows immediately. If the initial position $(x(0), m(0))$ of the system is on the vertical line $x = -r^*$, then the solution $(x(t), m(t))$ moves north-west and never returns to the steady state.

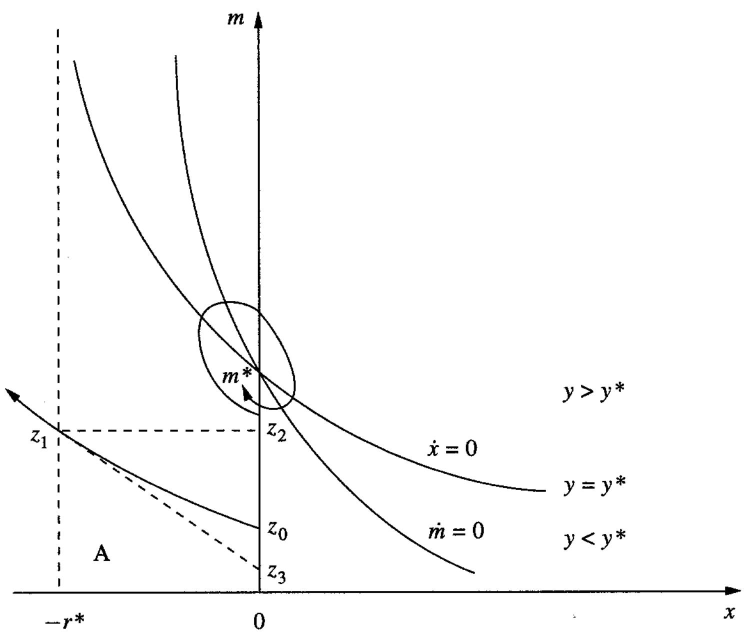

Fig. 1

However, one might be more interested in the movement of the system, when the initial position is at some point on the vertical line $x = 0$ below the steady state point. This corresponds to a situation where the system has been in the steady state for all $t < 0$, but at $t = 0$ it is disturbed by a contractionary shock, say a downward shift of the investment schedule $I(y, r)$ caused by a fall in long-run optimism. The effect of this is that the new steady state point $(0, m^*)$ has a higher m^* than the old, because r^* in the new steady state has to be lower than in the old, due to the shift of $I(y, r)$. Thus, immediately after the shock the economy is at a point, say $z_0 = (0, m_0)$, *below* the new steady state point $(0, m^*)$, as indicated in Fig. 1, now interpreted as showing the situation *after* the shock. Hence, at $t = 0$, $y < y^*$. Will this recession be self-correcting?

Proposition 1 (No recovery): Assume A1, A2, and A3. Let a recession as described above take place. Then there exists δ, $0 < \delta < 1$, such that for $m_0 \leq \delta m^*$ the solution $(x(t), m(t))$ with $(x(0), m(0)) = (0, m_0)$ never leaves the deflationary region[7] and y does not tend to y^* for $t \to \infty$.

For proof, see appendix A.

Corollary: If and only if the Cagan condition (14) holds, then a corridor exists.

Thus, according to this model the deflationary process set into motion by a deep slump does not create a return to full employment. The explanation is that the lower the nominal rate of interest has become during the slump, the more difficult it is to decrease it further. And as actual and expected inflation continue to fall, it becomes more and more likely that the real rate of interest will increase instead of decrease.[8] In this manner one might say that it is a *dynamic liquidity trap* which causes deep slumps to be self-sustaining.[9] Observe that no postulate of a "conventional," static liquidity trap — infinite interest elasticity

[7] The deflationary region is the region $A = \{(x, m) \in U \mid \dot{x} < 0, \dot{m} > 0\}$, cf. Fig. 1.

[8] Interestingly, in the boom there is no similar tendency for the stabilizing force to be weaker the further away from equilibrium the system is. On the opposite, $-L_i/L$ tends to be smaller, or at least not larger, the higher is the rate of interest. Indeed, in the case of constant numerical interest elasticity ϵ, $-L_i/L = \epsilon/i$, which is low when i is high.

[9] Confining his analysis to the problem of local stability, Johnson (1977) identified the phenomenon of a dynamic liquidity trap with the case of local instability ($-bL_i^*/m^* > 1$). The above shows, however, that even in case of local stability — and whatever the value of the interest elasticity of the demand for money — the system falls into a dynamic liquidity trap if subjected to a large contractionary disturbance.

of money demand — is involved. Likewise, no denial of the existence of and the possible local stability of a full employment equilibrium is involved. Nevertheless, if a recession is large enough, a dynamic liquidity trap is set in motion, preventing the recovery.[10]

In essentially the same model, Cugno and Montrucchio (1984) analyzed, by means of the Hopf bifurcation theorem, the related problem of the existence of periodic orbits surrounding the steady state. In view of the difficulty of establishing whether the "subcritical" case (the periodic orbit is attracting and occurs to the right of the bifurcation value of the control parameter, here b) or the "supercritical" case (the periodic orbit is repelling and occurs to the left of the bifurcation value) is present, this provided no concise condition as to the existence of a corridor. However, the Hopf bifurcation theorem is useful to give an idea of the boundary of the corridor when it exists. The theorem implies that for all b on the one side of the bifurcation value $\bar{b} = f_m^* m^*/f_x^* = -m^*/L_i^*$ and close enough to it, there exists a single periodic orbit surrounding the steady state with amplitude approximately proportional to $|b-\bar{b}|^{1/2}$ (use theorem A.20 in Azariadis, 1993, p. 156). When, in addition, (14) holds, we know a corridor exists and we may conjecture that its boundary can be identified with this periodic orbit. Then, since $\bar{b} = i^*/\epsilon^*$, where ϵ^* is the absolute value of the interest elasticity of money demand, given the equilibrium rate of interest i^*, the greater is ϵ^* the smaller is the "radius" of the corridor. It should be added that this is only a local claim pertaining to b sufficiently near to $\bar{b}$ ($b < \bar{b}$). I have not been able to *prove* — by means of, e.g., the Poincaré–Bendixson theorem — existence of a periodic orbit for b less than $\bar{b}$ and thereby that the corridor is bounded above.

4. Conclusion

We have established that in the simple Keynesian–monetarist model, prevalent in intermediate macroeconomic textbooks, the Cagan condition only entails *local* stability and is in fact, given the non-negativity of the nominal rate of interest, both a *necessary* and a *sufficient* condition for the existence of a corridor. This is an example of the limitations of local stability analysis as emphasized by the modern theory of non-

[10] Assumption A2 *(i)* excludes the Cagan demand for money function $L(y,i) = \psi(y)e^{-ai}$; $a > 0$. However, this function can only be valid for $i > 0$. At $i = 0$ money dominates bonds as an asset, and any amount of money $\geq \psi(y)$ should willingly be held. Proposition 1 can be extended to this case, see Groth (1993).

linear dynamical systems (see, e.g., Azariadis, 1993). Of course, the scenario of complete collapse of the economy and continuing deflation is not plausible. Apart from its all-round simplistic nature the model abstracts from monetary growth, the real balance effect, and the inflation tax. These matters tend to counteract the dynamic liquidity trap so that the economy tends sooner or later to be lifted from the floor. The model then becomes more like a business cycle model.

Appendix A
Proof of Proposition 1

Letting $n = \log m$, the system (12)–(13) is transformed into the equivalent system

$$\begin{aligned} \dot{x} &= b\varphi(f(x, e^n)) \ , \\ \dot{n} &= -x - \varphi(f(x, e^n)) \ , \end{aligned} \tag{A.1}$$

which is defined for all (x, n) in $\mathbb{R}^2$. The steady state of (A.1) is $(0, n^*)$, where $n^* = \log m^*$. Imagining that the phase diagram in Fig. 1 also portraits the third and fourth quadrants, we can think of it as the phase diagram of (A.1), interpreting m as n.

Consider a point on the vertical line $x = -r^*$ in Fig. 1, say the point $z_1 = (-r^*, n_1)$, where $n_1 < n^*$. Let t_1 be fixed. Denote by $z(t)$ the vector function $(x(t), n(t))$, and let $z(t, z_1)$ be the solution of (A.1) passing through z_1 at $t = t_1$, that is $z(t_1, z_1) = z_1$. The slope s of the corresponding trajectory in (x, n)-space is

$$s = s(x, n) = \frac{\mathrm{d}n}{\mathrm{d}x}(x, n) = \frac{\dot{n}}{\dot{x}} = \frac{-x}{b\varphi(f(x, e^n))} - \frac{1}{b} \ , \tag{A.2}$$

which is negative for $(x, n) \in \mathrm{A} \equiv \{(x, n) \in \mathbb{R}^2 \mid \dot{x} < 0, \dot{n} > 0\}$. Thus the solution curve $z(t, z_1)$ at $(x, n) = z_1$ points to the northwest in Fig. 1. Then, clearly $x(t) < -r^*$ for all $t > t_1$, for which the solution $z(t, z_1)$ is defined. Hence, to prove the proposition it is enough to prove that $z(t, z_1)$, when traced backward in time, crosses the half line $\{(x, n) \in \mathbb{R}^2 \mid x = 0, n < n^*\}$.

Let $z_1 z_2$ be the line segment $\{(x, n) \in \mathbb{R}^2 \mid -r^* \leq x \leq 0, n = n_1\}$. The continuous function $(x, n) \to s$ restricted to the nonempty compact set $z_1 z_2$ has a minimum, say $\bar{s}$, and $\bar{s} < 0$. Now, from (A.2)

$$\frac{\partial s}{\partial n} = \frac{x\varphi' f_m e^n}{b\varphi(f(x, e^n))^2} \leq 0$$

for $(x, n) \in Q \equiv \{(x, n) \in A \mid -r^* \leq x \leq 0, n \leq n_1\}$. Therefore $0 > s \geq \bar{s}$ for all (x, n) in Q, or $|s| \leq |\bar{s}|$ for all (x, n) in Q. The line through z_1 with slope $\bar{s}$ crosses the vertical line $x = 0$ at some point z_3. It follows that the solution $z(t, z_1)$ at some time $t_0 < t_1$ passes through some point, say $\bar{z} = (0, \bar{n})$, on the line segment $z_2 z_3$. Letting $\alpha = n^* - \bar{n}$ and $\delta = e^{-\alpha}$, the proposition is proved. Indeed, as $r(t) = i(t) - x(t) > -x(t) > -x(t_1) > r^*$ for all $t > t_1$, the solution for $y(t)$ is bounded away from y^*. Q.E.D.

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