

**High Inflation Dynamics:
Integrating Short-Run Accommodation
and Long-Run Steady-States**

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ABSTRACT

The paper develops a model for the analysis of high inflation phenomena. A central feature in of the model is the joint determination of the long-run steady-state rate of inflation and of the short-run dynamic process of inflation. The model includes a formal structure that is based on a simple, but powerful theorem: for a non-stationary (unit-root) inflationary process a price level shock eventually translates into a higher steady state rate of inflation which equals the ratio of the shock to the mean lag of inflation. The econometric approach is based on the apparent non-stationary behavior of the rates of change of the nominal variables in high inflation countries (prices, wages, exchange-rate and money). An application for the inflationary process in Israel during 1964-1993 is presented.

Inflationary phenomena have been dealt with separately by models that provide answers to two distinct questions: How is the rate of inflation determined in the long-run? And what is the nature of the short-run dynamic process of inflation?

The first question is typically discussed in the context of steady-state models of the "inflation-tax" variety. While conditions for the existence and stability of such (possibly multiple) equilibria have been studied, their dynamics out of equilibrium have, with a few exceptions, not been dealt with empirically. The second question, for which considerable empirical literature exists, is studied within models of short-run "wage, exchange-rate, price dynamics". While empirically successful for analysis of short-run dynamics such models usually leave long-run inflation out of the analysis, and are liable to the criticism of not providing a comprehensive rationale for the determination of the long-run rate of inflation.

The purpose of this paper is to develop a model that deals simultaneously with both questions. On the one hand, it rationalizes the fact that the steady-state rate of inflation depends on the dynamic inflationary process and therefore it is not possible to determine the long-run rate of inflation without understanding the short-run dynamics of inflation. And, on the other hand, the short-run dynamics of inflation are dependent on the expected long-run inflation, therefore it is not possible to determine the short-run dynamics of inflation without understanding the determination of the steady-state rate of inflation.

The starting point of our analysis in this paper is the well-known theoretical and empirical finding that in a world of unit root processes of inflation a one-time positive shock to the price level eventually leads to a permanent increase in the rate of inflation. The interesting issue, which so far has not been adequately analyzed, is the relationship that appears to exist between the structure of the dynamic process and the long-run inflation outcome. In other words the long-run steady-state is path-dependent, and vice-versa - the path (the dynamics) depend on the long-run, with inflationary accommodation to shocks playing a crucial role. These interdependencies will be analyzed here both from a theoretical and empirical point of view.

Our approach to the analysis of inflation takes into consideration general equilibrium conditions of the main markets. The interrelations between the product, labor, foreign exchange and the money markets¹ equilibrium and the dynamic of inflation are specifically modeled to capture all aspects of the inflationary process. In the empirical analysis we estimate only a single equation for inflation leaving out for the moment the complicated multi-market dynamics. In our analysis the long-run inflationary steady-state is not unique, clearing markets are an essential pre-condition for steady-state therefore non-uniqueness requires endogenous changes in different markets that are not fully modeled in this paper.² In section 1 we analyze the endogenous consequences of the non-stationary behavior of the rate of inflation. We propose a formal argument for the link between shocks and the dynamics of accommodation and the resulting rate of inflation. In section 2 we present a theoretical model that specifies the interrelation of the main markets and justifies the presence of a unit root in the rate of inflation. Section 3 presents the empirical analysis of the inflation process in Israel from 1964 until 1993. Concluding remarks are presented in the last section.

1. A THEOREM ON SHOCKS, ACCOMMODATION AND LONG-RUN INFLATION

To motivate the issues discussed in this section consider Figure 1 which fits a step regression line to the quarterly rate of inflation in Israel³ for the period 1964-1993 and the corresponding residuals (the estimates are given in appendix 1). The outstanding features of this regression are: As the rate of inflation accelerates the steps became steeper, the transition from one step to the next is relatively rapid and finally there is no sign of serial correlation in the residuals.

¹The equilibrium of the money market should be interpreted in broad sense, that is including the government long-run deficit and seigniorage needed for its finance.

² An example of this are the endogenous financial innovations that produce changes in the demand for money as describe in Melnick (1995).

³ See Bruno (1993) for a detailed analysis of the Israeli process.

What determines these steps in the inflation rate? We suggest and prove a theorem that links this size to both price level shocks and the nature of the dynamic process itself.

Consider the finite autoregressive representation of the inflationary process,

$$(1) \quad \pi_t = \sum_{i=1}^n \theta_i \pi_{t-i} + \varepsilon_t$$

where π_t is the rate of inflation in period t , θ_i are parameters of the dynamic process and ε_t is a stationary stochastic process. This is an autoregressive reduced form representation of a structural model that will be developed in the next section. Clearly a positive shock ε_t at time t_0 will have a positive effect on the rate of inflation. The effect will die out for a stationary process (roots outside the unit circle) and will have a permanent effect on the rate of inflation for a unit root process.

A greater degree of accommodation will be associated with greater inflationary inertia, namely a greater mass of the dynamic effects concentrated in recent periods. Greater inertia leads to greater inflationary persistence which, for the unit root case, will be permanent. We propose to show, for the unit root case, that a given initial shock leads to a proportionately bigger jump in long-run inflation the greater the degree of accommodation.

To clarify ideas let us first illustrate from some simple examples. Start with the first order autoregressive model,

$$(2) \quad \pi_t = \theta \pi_{t-1} + \varepsilon_t.$$

When $\theta < 1$, a one-time shock will cause inflation to follow a geometrically declining sequence which will die out. The higher is θ , i.e., the greater the degree of accommodation, the higher will be the inflation profile from any given initial shock. Thus there will be persistence but no permanent increase in the rate of inflation since the process

is stationary. When $\theta = 1$, we are in a random walk case and any positive shock will be fully and instantaneously transformed into a permanent increase in inflation.

Consider now a more interesting second order, unit root, autoregressive model with $0 < \theta < 1$,

$$(3) \pi_t = \theta\pi_{t-1} + (1-\theta)\pi_{t-2} + \varepsilon_t.$$

A one-time shock will cause an immediate increase in the inflation rate with subsequent fluctuations, at a decreasing amplitude, until inflation eventually settles on a new higher steady-state which bears a very simple relation to the coefficient θ . Assume π_0 is an arbitrary initial steady-state rate of inflation, then it is easy to show that the new steady-state after a shock of size ε is $\pi_0 + \Delta$ where⁴,

$$(4) \Delta = \frac{\varepsilon}{(2-\theta)}.$$

This simple result illustrates a key element in the relationship between the dynamics of inflation and its steady-state. For a given positive shock of size ε , the higher θ , namely the greater the degree of accommodation (i.e., more concentration of mass in the first lag) the higher is the new plateau of inflation. It turns out that the result obtained for this simple example is a special case of a much more general theorem.

Assume that the reduced form of the rate of inflation can be represented by an autoregressive process, as in (1), with a unit root,

$$(5) \sum_{i=1}^n \theta_i = 1$$

⁴This case is discussed in Bruno (1993). To prove the result consider the first difference of (3) $\pi_t - \pi_{t-1} = -(1-\theta)(\pi_{t-1} + \pi_{t-2}) + \varepsilon_t$. This constitutes an infinite geometric series with a first element equal to the shock ε_t and a ratio of $-(1-\theta)$, summing up to $\varepsilon_t / [1 + (1-\theta)]$.

and positive lag coefficients, $\theta_i > 0$. Denote by π_0 an initial steady-state rate of inflation. Define by Δ the difference between the new steady-state rate of inflation π_1 , obtained after a given one time shock of size ε at time t_0 . Following common usage define the mean lag as a time-weighted average of the coefficient θ_i :

$$(6) \quad \bar{\theta} = \sum_{i=1}^n i \theta_i$$

then, under the above assumptions, we get the following,

Theorem: There exists a new steady-state rate of inflation π_1 and the change in the steady-state rate of inflation $\Delta = \pi_1 - \pi_0$ equals the reciprocal of the mean lag times the initial shock.

Proof:⁵

Let us rewrite equation (1) using lag operator notation,

$$(7) \quad \pi_t = \theta(L)\pi_{t-1} + \varepsilon_t$$

where

$$(8) \quad \theta(L) = \theta_1 L + \theta_2 L^2 + \dots + \theta_n L^n$$

Applying the Beveridge-Nelson (1981) decomposition we obtain,

$$(9) \quad \pi_t = \theta(1)\pi_{t-1} + \theta^*(L)D\pi_{t-1} + \varepsilon_t$$

Since $\theta(1) = 1$ we get,

$$(10) \quad D\pi_t = \theta^*(L)D\pi_{t-1} + \varepsilon_t$$

where D is the first difference operator. The moving average representation of (10)

is,

$$(11) \quad D\pi_t = [1 - \theta^*(L)]^{-1} \varepsilon_t = A(L)\varepsilon_t$$

By algebraic manipulation one can show that

⁵This line of proof was suggested by James Stock. We would like to thank Zvi Artstein of the Weizmann Institute for providing us with a first proof of this theorem. For a reader who wants to avoid lag operators, a parallel relatively simple algebraic proof can be obtained by writing down sequentially $\pi_t - \pi_{t-1}$ for $t=1 \dots \tau$. Now sum up columns and let $\tau \rightarrow \infty$.

$$(12) A(1) = \frac{1}{\sum_{i=1}^n i\theta_i} = \frac{1}{\bar{\theta}}$$

Q.E.D

Two important implications of theorem 1 can be illustrated by analyzing two simple functional forms. In the first example $\theta_i = 1/n$, for all i . This is an equal weight (uniform) distributed lag model. The rise in steady-state inflation after a positive shock of size ε is $\Delta = 2\varepsilon/(n+1)$. In this example it is easy to see that the shorter the length of the lag n , the larger the rise in the steady-state rate of inflation. A limiting case is $n = 1$, a random walk model for which we know $\Delta = \varepsilon$.

In the second example $\theta_i = (1 - \lambda)\lambda^{i-1}$, this is an infinite geometric distributed lag model. The mean lag is $1/(1 - \lambda)$ and therefore $\Delta = \varepsilon(1 - \lambda)$. For this case it is easy to see that the smaller λ (i.e., more concentration of mass is in the first lag) the higher is the new plateau of inflation. In this case the jump to new steady-state takes place instantaneously so there is no dynamic adjustment as in the random walk case⁶. The shape of the distributed lag is an empirical issue that will be further elaborated in Section 3.

We have established that the shape of the distributed lag model of inflation influences the steady-state rate of inflation. We now want to establish that the long-run expected rate of inflation affects the shape of the distributed lag model. From a theoretical perspective the change in the θ 's as a result of a change in expected inflation is fully consistent with the Lucas's critique, since it is expected that the structural parameters underlying the reduced form parameters θ will adjust to changes in the long-run expected rate of inflation. The main empirical observation in this respect is the shortening of the inflationary dynamic adjustment process as a result of a rise in the rate of inflation, as shown in Bruno (1993).

⁶To show this let us assume, without loss of generality, a zero initial inflation and let $\varepsilon_{t_0} = 1$ be the size of the shock at time t_0 . By substituting we get $\pi_{t_0+1} = 1 - \lambda$. Again by substitution we get $\pi_{t_0+2} = (1 - \lambda)^2 + (1 - \lambda)\lambda = (1 - \lambda)$. By further substitution we obtain $\pi_{t_0+i} = (1 - \lambda)$ for all $i > 0$.

The shortening of the dynamic adjustment process and the rise of mass of the first lag can be interpreted as an endogenous rise in the degree of accommodation. This endogenous process manifests itself in numerous forms, such as increasing the frequency of cost-of-living compensation to wages, increasing the share of indexed assets in the financial portfolio, frequent adjustments of prices that are controlled by the government, indexation of contracts, frequent adjustments of the exchange rate, etc.

One may assume a continuous change in the θ_i s but still maintain the unit root property. An operational way of its modeling is to postulate a conditional density function, defined over the positive range, $f(\pi^e, x)$ where π^e , the long-run expected inflation, is the conditioning variable, then we may assume,

$$(13) \theta_i = \int_{i-1}^i f(\pi^e, x) dx \quad i = 1, 2, \dots, \infty$$

The specification of $f(\pi^e, x)$ is an empirical issue. Given the rapid transition from one step to the next presented in Figure 1, an exponential function would seem to be a good candidate for the empirical application.

The mechanism illustrated by the theorem is an essential element in the explanation of the increasing step-like function of the inflationary process under dynamic inflation such as in Israel during the 1970s and early 1980s. On the one hand a given shock results in a larger rise in the rate of inflation the shorter the lag of adjustment. But on the other hand, the lag of adjustment itself decreases when the rate of inflation accelerates. In the limit, as inflation accelerates it becomes a random walk.⁷ We now turn to a structural model from which the reduced-form autoregressive adjustment process (1) can be obtained while long-run inflation is also related to budget seigniorage finance.

⁷ The limiting process would be a hyperinflation in which inertia disappears.

2. THE MODEL

In this section and the next we discuss a structural model that is characterized by the simultaneous determination of the long-run steady-state equilibrium and the dynamic adjustment process. The purpose of the model is to provide an appropriate framework for the empirical analysis of inflationary processes in economies characterized by high and unstable rate of inflation. The structure of the model will be influenced by specific considerations regarding the stochastic properties and the stationarity or non-stationarity of different variables. We will show that considering the different stochastic properties of variables is not only required by econometric considerations but is a powerful tool for the formulation of the theory. In particular the different degrees of integration between nominal and real variables will play a central role in the distinction between the short-run and the long-run models and their interrelations.

A key feature of the model to be estimated in the next section is that the rate of inflation in the long-run can be stable only if there is a parallel equilibrium in the real sectors of the economy. The inflation rate can change its steady-state rate but its new equilibrium will not be stable until all markets reach an equilibrium. To model this type of interaction we will specify a long-run equilibrium condition for both the nominal and real aspects of the economy and a corresponding short-run dynamic adjustment process that converges to the long-run equilibrium. We first turn to long-run considerations.

The model consists of four markets: **The product** market provides an equilibrium condition for the long-run price level. This equilibrium will yield a basic cointegration relationship for the long-run rate of inflation. **The labor** market provides an equilibrium condition for the full employment real wage. **The balance of payments** provides a long-run equilibrium condition for the real exchange rate. And the **money** market together with the fiscal balance provides a long-run inflation tax equilibrium relationship.

Our point of departure is a conventional aggregate supply (AS) and aggregate (AD) demand framework. We assume an open economy producing a final good which competes with foreign goods and uses an importable intermediate import.

The balance between aggregate demand (AD) and aggregate supply (AS) of goods and services can be written in the following way:⁸

$$(14) \quad y^s \left(\frac{W}{P}, \frac{EP_R^*}{P}, A, \varepsilon_s \right) = y^d \left(\frac{M}{P}, \frac{EP_E^*}{P}, G, \varepsilon_d \right)$$

where P=price level, W=nominal wages, E=exchange rate, M=money, P_R^* =exogenous imported input prices, P_E^* =exogenous price of competing exports, A=long-run supply factors (capital stock and technological change), G=fiscal variable, ε_s and ε_d represent the random supply and demand shocks, respectively⁹.

Solving for the price level (P) we get:

$$(15) \quad P = P(W, E, M, P_R^*, P_E^*, A, G, \varepsilon_s, \varepsilon_d)$$

Given the underlying form of (14), the price equation (15) must be linearly homogeneous with respect to the nominal variables.

It is important to notice that the effect of the nominal exchange rate on domestic prices is the cumulative effect of the imported input prices and the export prices. While these prices have opposite effects on output they operate in the same direction on prices.

For theoretical and empirical reasons it is useful (particularly in a highly inflationary small open economy) to classify the variables in the price equation into three categories:

- (a) Domestic nominal variables (W, E and M).

⁸ The representation of this part follows the one given in Bruno, 1993, chapter 3. Formally, the supply schedule Y^S is obtained from a three-factor production function, equating marginal products of material inputs and of labor to their respective real market prices (see Bruno and Sachs, 1985). The demand schedule Y^D is obtained from a conventional open-economy IS-LM model, reflecting the combination of a money market equation with a Keynesian aggregate commodity demand schedule for consumption, exports and investments (with substitution for the interest rate).

⁹ Strictly speaking the aggregate demand function should include the expected rate of inflation.

(b) Foreign nominal variables (P_R^* and P_E^* that are denominated in foreign currency, and their rate of inflation is the world rate).

(c) Real variables (A includes productivity and capital stock trends, G the fiscal variables and the stochastic supply and demand shocks ε_s and ε_d).

At the theoretical level the price level P is undetermined unless one of the variables in category (a) is determined. Determination of either one of them can, in principle, serve as the anchor for the nominal system. The choice of the anchor is an important practical issue of economic policy, for instance the choice of W is not a practical one since most wages are not directly controllable by the government (with the exception of relatively short periods when a nation-wide credible nominal wage agreement can be achieved)¹⁰. The choice between M and E is more complicated and involves the issues of stability and control. Typically it is easier to control the exchange rate as compared with the control of the money supply. Which of the two is more effective in the short-run in anchoring the price level will clearly depend on the relative stability of the money demand and the process of financial innovation as compared with the openness of the economy and the share of imports and exports in the GNP, pressures on the reserves and speculative waves. The source of the shocks affecting the economy and the consequences of using M or E on the economy in relation to the different shocks will also matter.

For a highly inflationary economy the changes of the variables in (b) and (c) are of a totally different magnitude as compared with those in (a). Dramatic changes in the rate of change of the variables in category (a) can occur with no changes in the rate of change in those of category (b) and (c). This is a kind of dichotomy between the domestic inflationary process and the foreign inflationary process plus other real shocks.

From an empirical point of view it is quite clear that in a highly inflationary environment the stochastic processes that characterize the variables in category (a) are fundamentally different from those of categories (b) and (c). Specifically variables in category (a) are

¹⁰ See for example the wage agreement reached immediately after the stabilization program in Israel in 1985.

normally integrated processes of the second degree, $I(2)$, therefore only after twice differencing they become stationary processes. This means that the rate of inflation, the rate of devaluation, the rate of money growth and the rate of increase in nominal wages are not stationary processes. On the other hand the variables in categories (b) and (c), including the expected rate of inflation, are integrated processes of the first degree, $I(1)$, therefore after first differencing they become stationary processes (Table 2).

In what follows we will denote by lower-case letters the log of a variable, $\log(X) = x$ and the first difference in the logs by $Dx = \log(X_t) - \log(X_{t-1})$.¹¹

A log-linear approximation of (15) yields,

$$(16) \quad p = \tau_0 + \tau_1 w + \tau_2 e + \tau_3 m + v$$

where $\sum_{i=1}^3 \tau_i = 1$ and v is a log-linear combination of the variables included in (b) and (c).

This relationship is a cointegration relationship of rank (2,1), namely the variables are $I(2)$ and the "residuals" v are $I(1)$. By taking first differences of equation (16) we obtain our basic cointegration relationship,

$$(17) \quad \pi = \bar{\tau} + \tau_1 Dw + \tau_2 De + \tau_3 Dm + u$$

Where $\bar{\tau}$ is the mean of Dv and u is the deviation from its mean $u = Dv - \bar{\tau}$. It is clear from the previous discussion that all the variables in (17) are $I(1)$ and the residuals are $I(0)$ with $E(u) = 0$ and $\text{Var}(u) = \sigma_u^2$

Long-run equilibrium conditions for the real wage, real exchange rate and real balances could be derived formally. Since it is beyond the scope of the present study to specify a complete model we base our analysis on the conventional assumptions of existence of a long-run equilibrium and on stationarity of the deviations from it. We will denote the

¹¹ For consistency of the notation we will continue to denote the rate of inflation by $\pi = Dp$.

deviations of real wages, real exchange rate and real balances by S_i , $i=W,E,M$ respectively. In the empirical section we allow for different dynamics regarding possible multiple equilibrium in the seigniorage-type equilibrium models.

The basic assumption of the short-run model is that the short-run rate of inflation, real wage, real exchange rate and real balances could differ for extended periods from their long-run equilibrium. This will result in all kinds of rigidities or friction manifested inter alia in prolonged periods of unemployment, protracted imbalances in the current account and in the fiscal deficit. These deviations are assumed to be stationary and may exhibit large persistence. The convergence of these deviations to long-run equilibrium is not explicitly modeled. In the empirical application we compute these deviations and assume their convergence to zero. In a more general application the short-run adjustments could be specified as an error correction process as in Juselius (1992). The relative large shocks and the drastic changes in the Israeli economy make this a formidable job that, as mentioned, is beyond the scope of the present study; we therefore concentrate on a single equation approach to the inflation process.

The short-run dynamic adjustment for the inflation rate given in the cointegrated equation can be based on an error corrections specification of the type derived by Granger and Engle (1987) modified to include possible changes in the distributed lag coefficients of lagged inflation. Considering the feedback from the other markets the error correction should include not only the lagged residual of the long-run cointegration relationship of inflation but also the lagged residuals (S_i 's) of the deviation of the real wage, the real exchange rate and the real balances from their long-run levels. Then the general short-run dynamic inflation equation will be given by,

$$(18) \pi_t = \sum_{i=1}^n \theta_i \pi_{t-i} + \sum_{i=1}^{n1} \lambda_i DDe_{t-i} + \sum_{i=1}^{n2} \alpha_i DDm_{t-i} + \sum_{i=1}^{n3} \kappa_i DDw_{t-i} + \beta' Z_t \\ - \phi_p (\pi_{t-1} - \pi_{t-1}^e) + \phi_w S_{w_{t-1}} + \phi_e S_{e_{t-1}} + \phi_m S_{m_{t-1}} + \varepsilon_t$$

where Z is a stationary vector of exogenous variables and ϵ_t is white noise. θ_i is given by (7) and it is important to note that $\sum_{i=1}^n \theta_i = 1$. And π_{t-1}^e , the expected inflation, is defined as the long-run inflation calculated from the co-integrated equation (17).

A SIMPLIFIED MODEL

To further clarify our ideas it is best to think of the dynamic adjustment equation (18) as a reduced form that is obtained from aggregating over adjustment relations for the individual component nominal variables which are in turn homogenous in the inflation rates, reflecting accommodation to past or expected inflation. Allthough we do not specify and estimate the processes of the S_i 's, the simplified model developpe here can help to motivate our approach. Clearly the argument that the coefficients of adjustment rise with inflation, the cost of not adjusting more rapidly must be invoked. This can be done in the most straightforward way for wages and the exchange rate.¹² The change in nominal wages can usually be represented as a linear combination of indexation to past inflation (if there is a COLA in the economy) and the part of the wage contract which reflects expected inflation, while the exchange rate under high inflation may be adjusted by some kind of crawling peg rule, which of necessity will itself exhibit homogeneity with respect to lagged inflation. In both cases the relevant agents will want to increase the speed of adjustment to lagged inflation as inflation increases since otherwise their real objectives will not be optimized — the real wage will erode in the case of wage earners and the appreciating real exchange rate will erode the competitiveness of the economy.¹³

¹² When the exchange rate is an adjustable peg, money will in the short-run become endogenous and therefore need not be dealt with separately. There still remains the issue of long-run seigniorage equilibrium to which we return below.

¹³ We say optimized and not maximized because the real objective must be weighed against the social costs of higher inflation. The case of wage indexation is obvious — workers will want to keep their real wages unchanged yet nominal wage adjustments also involve some costs to the employer. The case of the particular crawling peg rule to be given below can be rationalized from short-run optimization in which the social cost function being minimized is

Rather than writing down the most general model we shall illustrate the issues in the context of a simplified model involving only prices, nominal wages and the exchange rate.

Price Equation

$$(19) \quad \pi_t = bDw_t + (1-b)De_t + Z_t^p$$

where Dw_t is wage inflation, De_t is the rate of devaluation and Z_t^p stands for price shocks.

Wage Equation

$$(20) \quad Dw_t = \alpha_1\pi_{t-1} + \alpha_2\pi_{t-2} + \alpha_3\pi_t^{ew} + Z_t^w$$

where $\alpha_1 + \alpha_2 + \alpha_3 = 1$, π_t^{ew} is the inflation expected by wage earners and Z_t^w represents unemployment, productivity and wage shocks. A three-period specification is chosen to allow for greater indexation to most recent inflation as inflation accelerates, i.e. α_1 will rise with π .

We now assume for simplicity that inflationary expectations for wage earners are represented by expected devaluation which can in turn be gauged from a known exchange-rate rule (see below).

$$(21) \quad \pi_t^{ew} = De_t$$

quadratic in terms of the deviation of inflation from the existing rate and the deviation of the real exchange rate from the current account equilibrating rate. The relative weight put on current account erosion will rise as inflation rises. The details are given in Bruno (1991).

Exchange-Rate Rule

$$(22) \quad De_t - De_{t-1} = \beta_0 + \beta(\pi_{t-1} - \pi_{t-1}^* - De_{t-1}) + J_t$$

where π_t^* stands for world inflation, or

$$(23) \quad De_t = \beta\pi_{t-1} + (1-\beta)De_{t-1} + Z_t^c$$

where $Z_t^c = \beta_0 - \beta\pi_{t-1}^* + J_t$.

J_t is a dummy variable representing occasional step devaluation and β will rise with inflation, *i.e.* $\beta = \beta(\pi) \leq 1$.

Substituting De_{t-1} into (23) and assuming that $(De_{t-2} - \pi_{t-2})(1-\beta)^2 \cong 0$ (in order to truncate the process beyond $t-2$) we can simplify (23) to become:

$$(24) \quad De_t = \beta\pi_{t-1} + (1-\beta)\pi_{t-2} + [Z_t^c + (1-\beta)Z_{t-1}^c]$$

Substituting (20) (21) and (24) into (19) we get:

$$(25) \quad \pi_t = \theta\pi_{t-1} + (1-\theta)\pi_{t-2} + Z_t$$

where $\theta = b\alpha_1 + [1 - b(\alpha_1 + \alpha_2)]\beta$ and $Z_t = [1 - b(\alpha_1 + \alpha_2)](Z_t^c + Z_{t-1}^c) + Z_t^p + bZ_t^w$

We get the following results:

1. (25) is a simple second order autoregressive model with a unit-root as given in (1) and (18).
2. The residual term Z_t reflects exogenous shifts and error terms from all three nominal processes, as one would expect.

3. If α_1 increases with inflation (higher level of wage indexation to the last period) and likewise the speed of exchange-rate adjustment (β) increases with inflation, so will the coefficient of adjustment (θ) in the unit-root process (25). This follows from straightforward partial differentiation of θ

$$\frac{\partial \theta}{\partial \alpha_1} = b(1 - \beta) \geq 0 \text{ and } \frac{\partial \theta}{\partial \beta} = 1 - b(\alpha_1 + \alpha_2) > 0$$

4. For any one-time shock ε in Z_t we get in the long-run, $\Delta\pi = \varepsilon/(2-\theta)$ as the Theorem in section 1 claims. (The simple proof for the second order model case is given in footnote 1).

Consider a numerical example. Suppose $b = 0.4$ and consider hypothetical values for β , α_1 , α_2 under low inflation (I), high inflation (II) and hyperinflation (III).¹⁴ We have:

Table 1

	Low Inflation	High Inflation	Hyperinflation
	I	II	III
β	0.5	0.8	1
α_1	0.3	0.8	0
α_2	0.5	0.1	0
θ	0.46	0.83	1
$1/(2-\theta)$	0.65	0.85	1

Now let us link the inflation rate with the underlying long-run determinants of seigniorage and steady-state inflation.

¹⁴ We assume all wage indexation stops under hyperinflation so wages are entirely expectations driven, while the exchange rate adjusts fully and instantaneously to inflation.

Assuming that the alternative to holding money is foreign exchange and assuming a semi-log demand function for money we have for base money demand (H_t^d)

$$(26) H_t^d = P_t Y_t \exp(-\gamma De_t)$$

For the rate of change of base money demand (μ_t^d) we get:

$$(27) \mu_t^d = \pi_t + Dy_t - \gamma(De_t - De_{t-1})$$

If g_t is the domestic deficit to be financed by seigniorage we get for the base money supply (rate of change μ_t^s):

$$(28) \mu_t^s = \frac{\dot{H}_t^s}{H_t} = \frac{\left(\frac{\dot{H}}{PY}\right)_t^s}{\left(\frac{H}{PY}\right)_t} = g_t \exp(-\gamma De_t)$$

μ_t^d and μ_t^s , which can in turn be expressed in terms of π_{t-1} , π_{t-2} and π_{t-2} (using (24)), need not be in equilibrium except in the long-run, as g_t for example, was subject to shocks.

The feedback in the dynamic system can be completed by making $(\mu_t^d - \mu_t^s)$ affect the pressure to cause a one-time jump in the exchange rate (changing J_t momentarily in (22)).

When $\mu^d > \mu^s$ there is pressure to appreciate (J negative). When $\mu^d < \mu^s$ there is pressure to depreciate (J positive). Thus, a disequilibrium in the basic long-run money deficit finance relationships will help to move inflation to simultaneous equilibrium in the other markets, so that the long-run inflation rate will also be consistent with budget balance.

3. EMPIRICAL ANALYSIS

The empirical analysis is based on a thirty year quarterly sample of Israeli data. It starts in the first quarter of 1964 and ends in the last quarter of 1993 (120 quarterly observations). The variation in the data is very large and there is a wide range of inflationary experience, having gone from single to double and triple digit inflation back to almost single digits, allowing for an almost laboratory environment of econometric analysis and hypothesis testing (Figure 1). Tests for unit root of the key variables of our model are presented in Table 2. We do not reject the hypothesis of a unit root in the (log) levels and in the first (log) differences (with or without trend) of all the nominal variables. For the second (log) differences the hypothesis is rejected for all the variables. This empirical evidence strongly supports the key assumptions in the development of the structural model presented in the previous section.

The long-run expected inflation is defined as the rate of inflation determined by the basic cointegration relationship of inflation (equation 17). Estimating this relationship we obtain,

$$(29) \quad \pi^e = \underset{1.6}{.006} + \underset{12.7}{.56}De + \underset{6.9}{.32}Dw + \underset{2.5}{.09}Dm$$

with $R^2 = .92$, and one cannot reject the hypothesis that the residuals of this equation are stationary and therefore the hypothesis of cointegration is not rejected. The fit of this long-run relationship is presented in Figure 2, despite the remarkable changes in the inflationary process over the period the estimated coefficients seem to fit well in all the sub-periods. Our interpretation of this finding is that the rate of change in prices, exchange rate, wages and money are structurally related (see equation 17). As Israel is a small open economy, it is not surprising to find that the long-run elasticity of inflation with respect to the exchange rate is .56. The corresponding elasticity with respect to wages is .32 and with respect to the money supply is only .09. The sum of the coefficients is .97, almost identical to 1 as

required by the basic homogeneity restriction. We take the residuals of this equation (to be denoted by S_p , see Figure 2), to be a measure in each period of the deviation of the actual short-run rate of inflation from the long-run expected rate of inflation, as previously defined.

The long-run price equation is consistent with goods market clearing. A key feature of our approach is that the rate of inflation in the long-run can be stable only if there is parallel equilibrium in all the other markets of the economy. The inflation rate can change its steady-state rate but its new equilibrium will not be stable until all markets clear. Empirically the dynamic adjustment of the rate of inflation to its long-run expected level depends not only on the size of S_p but also on the possible dynamic adjustment of the labor market, foreign exchange market and the money market to their long-run equilibria, the latter defined as the level of real money base that is consistent with the fiscal budget deficit. As long as there is long-run disequilibrium in any of these markets the short-run dynamic adjustment of the rate of inflation will continue.

To estimate the short-run dynamic inflation equation we must therefore provide an empirical measure of the disequilibria in each of the three markets.

Table 2:
Unit Root ADF Tests^a

	Log Levels		First Differences		Second Differences
	Nominal	Real ^b	With trend	Without trend	
Prices	-2.30	-	-1.76	-1.89	-7.15 ^c
Wages	-2.28	-4.04 ^c	-2.13	-2.19	-8.97 ^c
Exchange Rate	-2.05	-3.28	-2.16	-2.23	-7.09 ^c
Money	-1.84	-0.97	-2.61	-2.60	-8.61 ^c

^a Prices - Consumer Price Index. Wages - wages per employee post. Exchange rate - basket NIS., Money - M2

^b Deflated with the CPI

^c Unit root hypothesis rejected at 5 percent level

The Labor Market

We will define the disequilibrium in the labor market as the gap between the long-run supply and demand for labor, or the deviation of the unemployment rate from its "natural" long-run rate. It is beyond the scope of this paper to provide a comprehensive analysis of the labor market, therefore we capture this disequilibrium as the gap between of the long-run trend in real wages and the actual real wage. Real wages are measured as the log of the ratio of wages per employee and the consumer price index. In principle we would expect that the long-run real wage will be proportional to labor productivity but despite the fact that Israel has experienced drastic changes in the rate of labor productivity growth the hypothesis that the real wage is well represented by a deterministic time trend can not be rejected. This finding (see also Melnick, 1994) can be interpreted as a long-run real wage rigidity. The fitted trend is given by,

$$(30) \quad w - p = \frac{2.8}{171.9} + \frac{.006}{35.8} t$$

with $R^2 = .92$, where t is a time trend. In Figure 3 we plot the real wage, the long-run trend and the residuals, the latter to be denoted by S_w .

The Foreign- Exchange Market

Similarly to our measure of the long-run disequilibrium in the labor market, and for analogous reasons, we define the disequilibrium in the foreign-exchange market as the gap between the trend real exchange rate and the actual real exchange rate, measured as the log of the ratio of the mean import and export price deflators (including taxes and subsidies) and the consumer price index (using other deflators in the denominator like the GDP deflator does not alter the main findings in any way). In a recent paper Meridor and Pessach (1993) presented a structural cointegration analysis of the real exchange rate. One of their major findings is the break in the long-run trend of the real exchange rate after the liberalization of the exchange market at the end of 1977; this break can be the main

reason for not rejecting the presence of a unit root in the real exchange rate (an explanation of this break is given there). For our purposes we computed two time trends, before and after the last quarter of 1977. The fitted trends are given by

$$(31) \quad e - p = \underset{-463.5}{-5.2} + \underset{14.1}{.005}t + \underset{35.0}{1.0}D_{78} - \underset{-30.5}{-.01}t_{78}$$

with $R^2 = .91$, where D_{78} is a dummy variable equal to zero before 1978 and 1 after, t_{78} equal the product of t and D_{78} . In Figure 4 we plot the real exchange rate, the fitted long-run trends and the residuals, the later to be denoted by S_e . An interesting empirical finding is the high correlation between S_e and the residuals obtained by Meridor and Pesach in their cointegration equation.

The Money Market

Our definition of the long-run-money market disequilibrium introduces the government deficit into the analysis. Define by g the long-run fiscal deficit as a ratio of GDP, by h the money base ratio and by Dy the real rate of growth. As is well known the long-run equilibrium is given by

$$(32) \quad g = (\pi + Dy)h$$

where π is the rate of inflation that is consistent with the long-run required seigniorage. In our model this rate of inflation is identical in the long-run to the rate of inflation given in equation (29). The money base disequilibrium is defined as

$$(33) \quad S_m = g - (\pi + Dy)h$$

Since we do not have quarterly data on the fiscal deficit we compute S_m using annual data and assume an equal disequilibrium during the year. The calculation is presented in Table 3.

As is well known the rate of inflation that solves equation (32) need not be unique (see for example, Bruno and Fischer, 1990). In particular if the elasticity of the demand for real balances is greater than unity a pathological high rate of inflation may be stable. There is substantial amount of evidence showing that in Israel the elasticity was greater than one when the rate of inflation exceeded 100 percent at annual rate (Melnick 1988 and 1995). Depending on the actual level of inflation, a disequilibrium in the money market, as defined, may have opposite effects on the rate of inflation. For low inflation, a positive S_m will have a positive effect on the rate of inflation while for high inflations it may be negative. This different dynamic relationship is illustrated by the arrows in Figure 5.

The dynamic short-run adjustment equation of the rate of inflation is an error correction equation, consistent with the Engel and Granger (1987) representation theorem (equation 18). This equation is expanded to include the two basic features of our model. First, the stationary long-run disequilibrium measures of the labor, exchange rate and money markets (S_w , S_e and S_m) are included with one lag. The latter is split into two variable S_{ml} and S_{mh} , where $S_{ml} = S_m$ if $\pi < .20$ and zero otherwise and $S_{mh} = S_m$ if $\pi \geq .20$ ¹⁵ and zero otherwise. The inclusion of these variables guarantees that the dynamic adjustment of inflation will continue until the labor, exchange rate and money market reach a long-run equilibrium, namely $S_w = S_e = S_m = 0$. Clearly, the short-run equation includes S_p with a lag, the error correction term. The inclusion of S_p guarantees that π converges to the long-run expected inflation given by the cointegration relationship. That particular rate is the rate of inflation that synchronizes all the nominal variables of the system. It is quite clear that if $S_m = S_p = 0$ then the inflation rate is consistent with the rate that produces the required seigniorage level (defined by the demand for money base and the fiscal deficit) and with the rate that synchronizes all the nominal variables in the economy. The latter feature enables the integration of the two separate (long-run steady-state and short-run dynamic) approaches to the analysis of high inflation. The second important feature of our

¹⁵ Note that π is measured on a quarterly basis. Thus .20 corresponds to an annual rate of about 100 percent.

Table 3
Money Market Disequilibrium

Year	Domestic Fiscal Deficit % of GDP (1)	Money Base % of GDP (2)	GDP Growth % (3)	CPI Inflation % (4)	Seigniorage % of GDP [(3)+(4)]*(2) (5)	Money Market Disequilibrium (1)-(5) (6)
1964	-5.6	13.3	9.8	5.2	2.0	-7.6
1965	-2.8	12.5	9.4	7.7	2.1	-5.0
1966	-1.0	12.0	1.0	8.0	1.1	-2.1
1967	4.5	14.3	2.3	1.6	0.6	3.9
1968	6.4	15.1	15.4	2.1	2.6	3.7
1969	4.1	13.6	12.8	2.5	2.1	2.0
1970	2.9	12.7	7.8	6.1	1.8	1.2
1971	1.8	13.7	11.1	12.0	3.2	-1.3
1972	5.1	15.7	12.5	12.9	4.0	1.1
1973	11.3	14.1	4.8	20.0	3.5	7.8
1974	14.1	10.8	5.6	39.7	4.9	9.2
1975	15.0	9.5	3.9	39.3	4.1	10.8
1976	7.7	8.2	1.6	31.3	2.7	5.0
1977	11.9	9.1	1.9	34.6	3.3	8.6
1978	10.3	7.2	4.0	50.6	3.9	6.4
1979	10.4	4.7	4.6	78.3	3.9	6.5
1980	12.7	3.2	3.0	131.0	4.3	8.4
1981	16.9	2.7	4.6	116.8	3.2	13.6
1982	10.2	2.5	1.3	120.3	3.0	7.1
1983	8.4	2.3	2.6	145.7	3.4	5.1
1984	18.7	1.9	2.1	373.8	7.0	11.6
1985	7.1	4.3	4.3	304.6	13.3	-6.2
1986	0.2	6.1	4.1	48.1	3.2	-3.0
1987	1.2	7.1	6.1	19.9	1.8	-0.6
1988	4.0	5.7	3.2	16.3	1.1	2.9
1989	7.6	4.7	1.1	20.2	1.0	6.6
1990	6.5	4.1	6.0	17.2	0.9	5.6
1991	7.0	3.7	6.2	19.0	0.9	6.0
1992	5.7	3.6	6.7	11.9	0.7	5.0
1993	3.5	4.1	3.4	10.9	0.6	2.9

model is that the dynamic adjustment coefficients of the inflation lags are allowed to change as a function of the long-run expected inflation maintaining their sum to unity. These two features of the model connect the long-run equilibrium inflation with the short-run dynamics. A rise in the long-run expected rate of inflation shortens the length of the lag and increases the weight of most recent lags. This process converges to a random walk when the inflation rate accelerates. The estimated equation should be interpreted as a reduced form of a complete short-run dynamic structural form that implicitly incorporates the dynamic adjustment of wages and the shortening of the cost of living compensation as inflation accelerates, the dynamic adjustment of the exchange rate and money supply policy reaction functions as well as other endogenous market changes, like the rise in the rate of financial innovation (Melnick 1995) when the rate of inflation rises.

This reduced form can be written in the following way:

$$(34) \quad \pi_t = \sum_{i=1}^n \theta_i (\pi_{t-i}^e) \pi_{t-i} + \phi_p S_{p,t-1} + \phi_w S_{w,t-1} + \phi_c S_{c,t-1} + \phi_{ml} S_{ml,t-1} + \phi_{mh} S_{mh,t-1} + B'Z_t + \varepsilon_t$$

where,

$$(35) \quad \theta_i (\pi^e) = \begin{cases} (1 - e^{-\lambda \pi_{t-1}^e}) e^{-(i-1)\lambda \pi_{t-1}^e} & i < n \\ e^{-(i-1)\lambda \pi_{t-1}^e} & i = n \end{cases}$$

This specification corresponds to equation (13) where f is an exponential density function with parameter $\lambda \pi_{t-1}^e$. Z is a vector of relevant stationary variables and n is the maximum lag length. After some experimentation the variables included in Z were the acceleration of the rate of devaluation (with a coefficient β_1) and a dummy variable for the price freeze during the package deal of 1984 (with a coefficient β_2).

The estimated parameters are (t-values are shown in parenthesis):

$$\lambda = 11.2 (2.7)$$

$$\begin{aligned}\phi_p &= -0.28 (-2.3) \\ \phi_e &= 0.18 (15) \\ \phi_w &= 0.26 (4) \\ \phi_{ml} &= 0.0009 (1.4) \\ \phi_{mh} &= -0.0013 (-1.0) \\ \beta_1 &= 0.20 (3.5) \\ \beta_2 &= -0.35 (-10.5)\end{aligned}$$

with $R^2 = .90$ and $DW = 1.9$.

We note that while the signs of θ_{ml} and θ_{mh} seem to conform to our prior expectations, the coefficients themselves are not highly significant. One should remember that our deficit data are based on engineered quarterly observations. Another consideration is that the deficit, while treated as exogenous, is in fact partly endogenous to the inflationary process (there were, for example, Tanzi effects in spite of the fact that the tax system was on the whole indexed). It is not clear how to take that into account empirically or in what direction that would affect the estimates.

With the estimated parameter λ we can compute the distributed lag coefficients θ_i for different levels of expected inflation, Table 4.

Table 4
Estimated Lag Coefficients

Expected Inflation (Annual Rate %)	First Lag	Second Lag	Third Lag and More
	θ_1	θ_2	θ_3
10	0.24	0.18	0.57
40	0.67	0.22	0.11
100	0.89	0.10	0.01
400 and more	1.00	0.00	0.00

For relatively low inflations, 10 percent annual rate, there is a long tail in the distributed lag coefficients, 0.57 of the distribution comes after and including the third lag. As the rate of expected inflation accelerates, the length of the lag shrinks, climbing rapidly to 0.9 for the first lag at 100 percent. Above 400 percent annual rate, the rate of inflation becomes a random walk.

4. CONCLUDING REMARKS

The framework suggested here seems to suggest an internally consistent way of relating both the long-run and the short-run adjustment processes in the course of varying inflationary experience while at the same time suggesting a rationale for the inherent instability of chronic high inflation coming from the way it accommodates to various types of shocks. For the case of Israel, given here, the parsimonious model and the empirical estimates make considerable sense.

There are nonetheless ways in which the empirical estimates could be further improved upon. We note the weakness of the empirical link with deficit finance, while intuition suggests that the fiscal fundamentals must have played an important role both at the start of the high inflation and also in bringing it to an end. It may be that exchange-rate behavior which was quite central to the process, also proxies for some of the underlying fiscal changes. Another limitation of the present empirical estimates comes from the fact that the adjustment of coefficients to rising inflation was done within the reduced form rather than introduced explicitly into the underlying structural wage and exchange rate adjustment processes.¹⁶ Another issue worth looking into both from a theoretical perspective and in terms of empirical estimation is the way the behavior of financial asset markets can be integrated into the general framework in a more comprehensive way.

¹⁶ Some of that was given in an earlier paper by one of the authors (Bruno, 1989).

More generally one could try to apply this type of model to similar protracted inflationary episodes such as in some of the Latin American cases to see whether similar stochastic and dynamic specifications can be obtained in inflationary processes that in many ways resembled the Israeli one.

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Figure 1. A Step Regression Line of Israel's Inflation
1964 - 1993

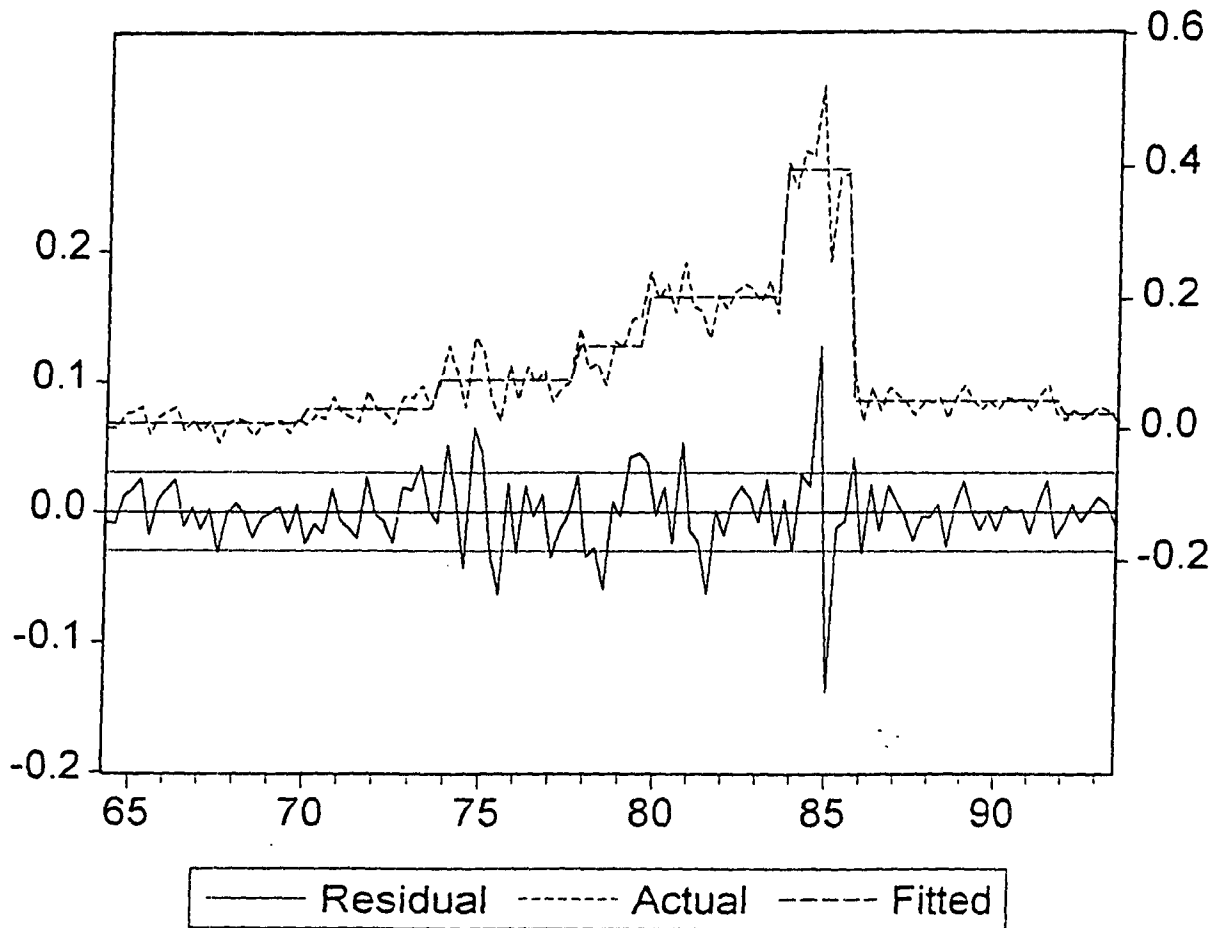


Figure 2. Actual and Expected Long-Run Inflation
1964 - 1993 (Residuals = S_p)

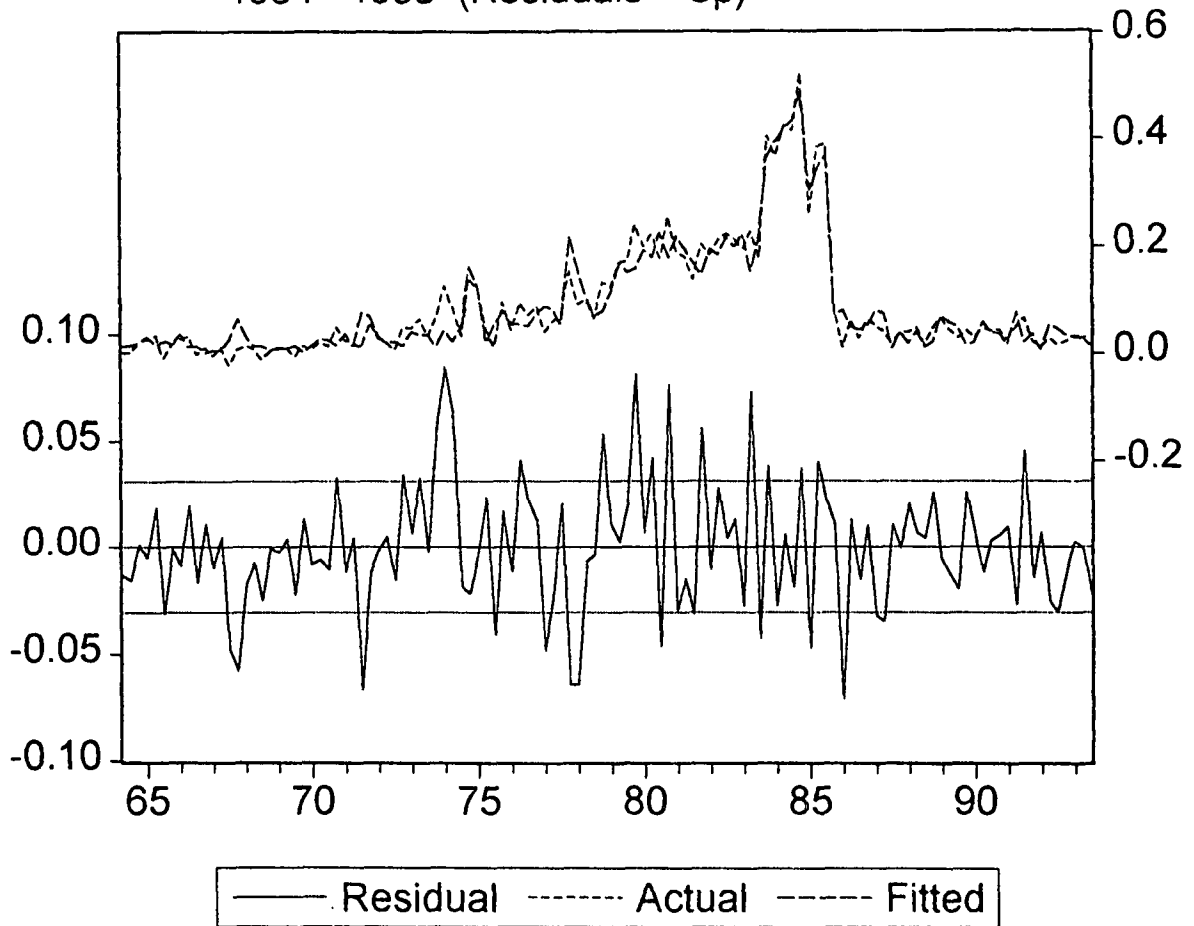


Figure 3. Real Wages and Real Wages Long-Run Trend
1964 - 1993 (Residuals = Sw)

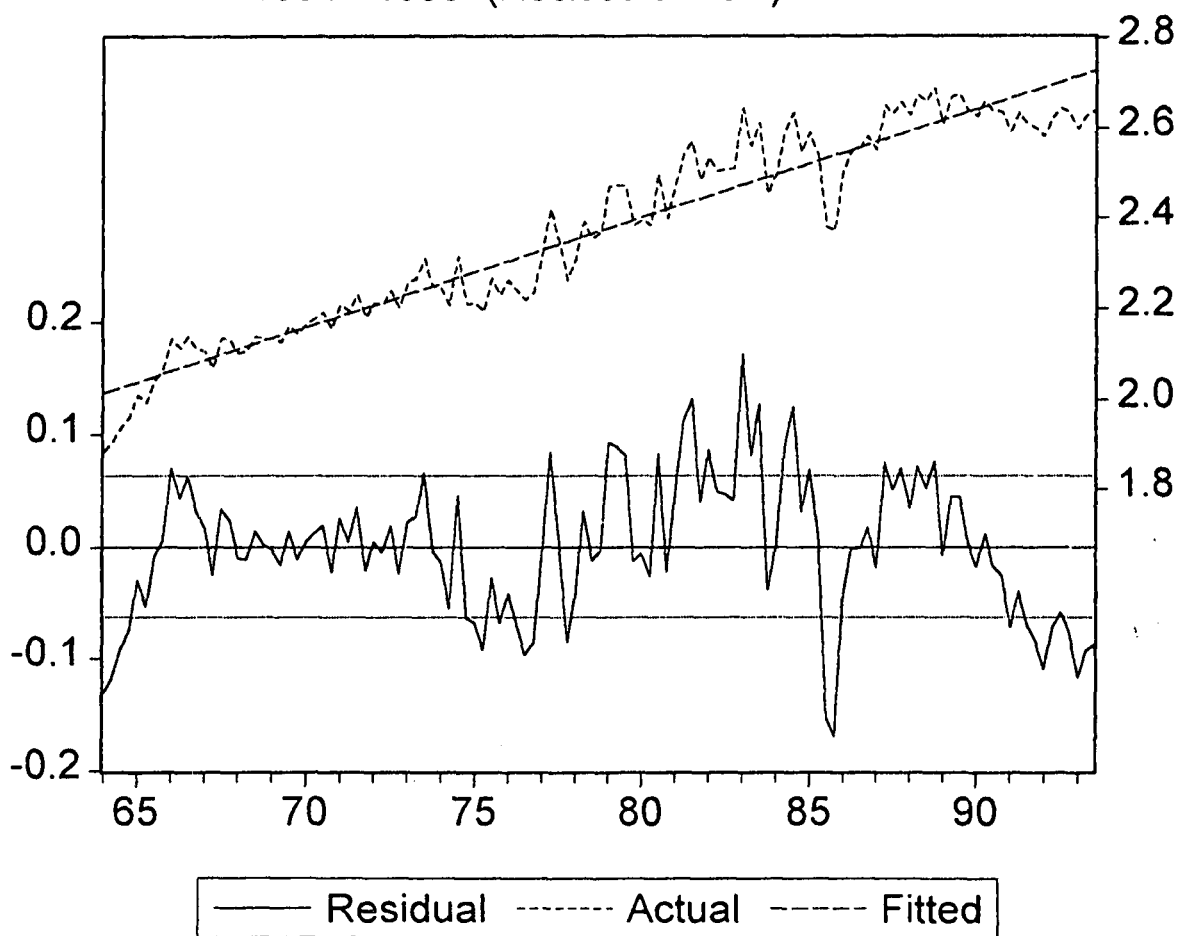


Figure 4. Real Exchange Rate and Real exchange Rate Trend
1964 - 1993 (Residuals = Se)

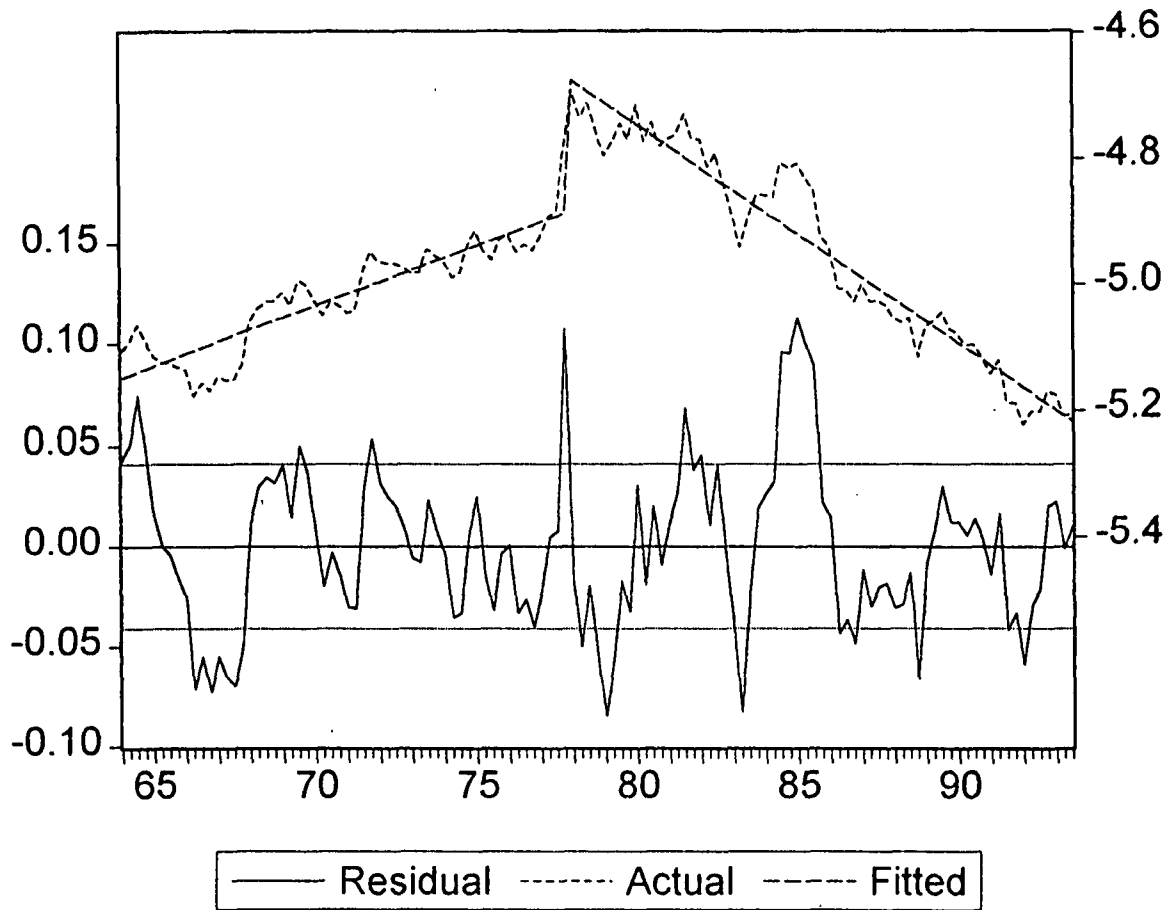
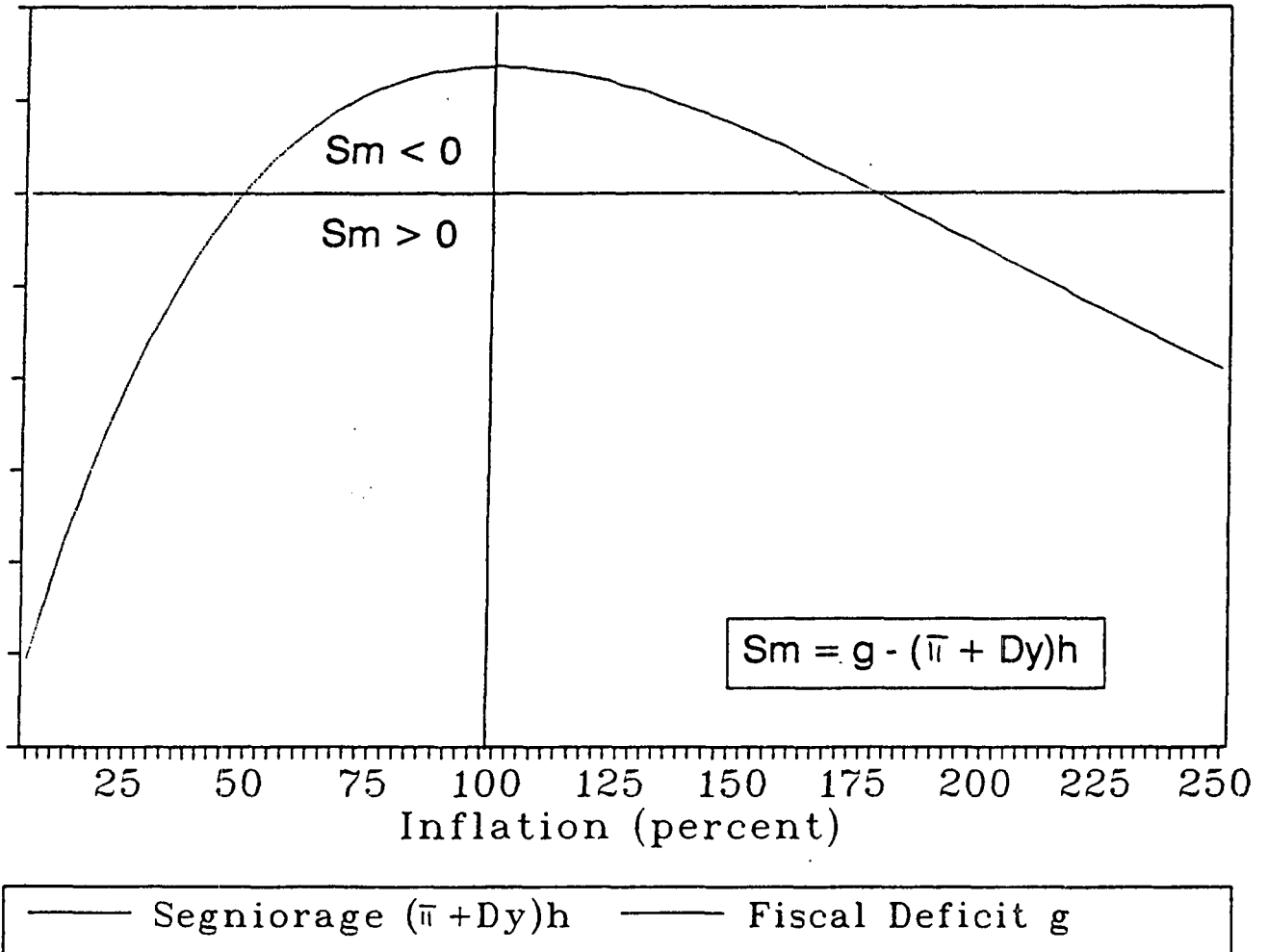


Figure 5. Fiscal Deficit, Segniorage and the Rate of Inflation



Appendix 1.

A step Regression line of Israel's Inflation
'1964 - 1993'

LS // Dependent Variable is DP

Date: 06/19/95 Time: 15:04

LS // Dependent Variable is DP

Included observations: 118 after adjusting endpoints

Variable	Coefficient	Std. Error	T-Statistic	Prob.
C	0.010172	0.006162	1.650843	0.1016
S73	0.021668	0.009807	2.209414	0.0292
S77	0.066700	0.009620	6.933567	0.0000
S79	0.117772	0.012129	9.709777	0.0000
S83	0.193211	0.009620	20.08454	0.0000
S85	0.385925	0.012129	31.81776	0.0000
S91	0.033408	0.008538	3.912914	0.0002
S93	0.012680	0.012756	0.994034	0.3224
R-squared	0.928760	Mean dependent var	0.090148	
Adjusted R-squared	0.924227	S.D. dependent var	0.107350	
S.E. of regression	0.029550	Akaike info criterion	-6.977935	
Sum squared resid	0.096054	Schwartz criterion	-6.790092	
Log likelihood	252.2634	F-statistic	204.8688	
Durbin-Watson stat	2.341509	Prob(F-statistic)	0.000000	
s73 = 1 if 70:1 <= t <= 73:3 and 0 otherwise				
s77 = 1 if 73:4 <= t <= 77:3 and 0 otherwise				
s79 = 1 if 77:4 <= t <= 79:3 and 0 otherwise				
s83 = 1 if 79:4 <= t <= 83:3 and 0 otherwise				
s85 = 1 if 84:4 <= t <= 85:3 and 0 otherwise				
s91 = 1 if 85:4 <= t <= 91:4 and 0 otherwise				
s93 = 1 if 92:1 <= t <= 93:3 and 0 otherwise				

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