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Nominal and Real Disturbances and Money Demand in the Chinese Hyperinflation

Ellis W. Tallman, De-piao Tang, and Ping Wang

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Ellis W. Tallman, Federal Reserve Bank of Atlanta
De-piao Tang, Hong Kong University of Science and Technology
Ping Wang, Vanderbilt University and National Bureau of Economic Research

Abstract: This paper reexamines the dynamics of hyperinflation by allowing variability in the relative price of capital goods in units of consumption goods that reflects interactions between the real and monetary sectors. The theory generates empirically testable implications that suggest expanding the standard Caganian money demand function to include both anticipated inflation and relative price effects in a nonlinear fashion. Employing data from the post–World War II Chinese hyperinflationary episode, the empirical findings suggest that conventional econometric investigations of money demand during hyperinflation overlook important nonlinear interactions between real and monetary activities and, hence, underestimate the welfare costs of hyperinflation.

JEL classification: E31, E41

Key words: hyperinflation, money demand

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1.   Introduction

The analysis of historical episodes of hyperinflation typically concentrates on the impact on money demand from anticipated inflation arising from the over-issuance of fiat money. Yet, it is possible that prices increase at different rates across sectors, giving rise to redistribution effects. In theoretical models of money and inflation, it is generally assumed that all prices change equi-proportionately. As a consequence, the potential effect of real disturbances through *relative price changes* on money demand is usually ignored. Although this omission was questioned almost two decades ago by Policano and Choi (1978), little attention has been paid to assessing the importance relative price effects on money demand during hyperinflation in addition to the influence of anticipated inflation.[1]

The present paper re-examines money demand during hyperinflation using a model that allows the relative price of capital goods to vary. We assume that fluctuations in the relative price reflect interactions between the real and monetary sectors. In particular, we propose alternative estimates for Caganian money demand, taking into account both anticipated inflation and relative price effects in a *nonlinear* fashion based on a dynamic monetary model. This exercise highlights how conventional money demand econometric investigations overlook nonlinear interactions between the real and monetary activities, and hence, may under-estimate the true welfare costs of hyperinflation. We develop a dynamic model with infinitely lived, perfect foresighted agents. Money is introduced into the model through a general cash-in-

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[1]   Recently, Rogers and Wang (1994) and Tallman and Wang (1995) investigate empirically whether there are equi-proportionate movements in inflationary episodes. Rogers and Wang (1994) find significant movements in relative prices in post-WWI France and Germany as well as the Israeli and Latin American economies in the 1980s. Tallman and Wang (1995) further contrast the post-WWI German and the post-WWII Chinese hyperinflation

advance constraint.[2] In contrast to Lucas (1980) and Stockman (1981), we follow Wang and Yip (1992) assuming that all consumption goods and a fraction of capital goods require cash services prior to their transactions. Thus, capital and consumption goods are distinct goods, so there is a non-trivial relative price of the capital good in terms of the consumption good. In this model, we also incorporate the variable velocity setup developed in Tallman and Wang (1995) in order to capture the explosive hyperinflationary spiral, including among others the debt-inflation spiral implicitly. Thus, the theoretical framework in this paper generalizes the models extant in the literature.

In accordance with the conventional literature, we regard hyperinflations as primarily monetary phenomena. For analytic convenience, we assume that the money creation process is exogenous, which simplifies greatly our analysis. Hence, the monetary authority is assumed not to respond directly to fiscal authority's demand for seigniorage revenue. Although this eliminates the possibility of a debt-inflation spiral, the model can account for a debt-inflation spiral without altering qualitatively the theoretical predictions. While the anticipated inflation rate reflects intertemporal price changes, the relative price of the capital good captures contemporaneous price variations. Our theory concludes that money demand depends negatively on both the anticipated inflation rate and the relative price of the capital good to the consumption good. But there may also be interactive effects among these factors. As a consequence, relative price movements have an ambiguous effect on how money demand responds to anticipated

experiences in the impulse responses of money and prices.

[2]   Policano and Choi (1978) modified the traditional inventory model of money demand by allowing multiple transacted goods; they found that the effect of the level of relative prices on money demand is ambiguous in sign. This real disturbance effect depends in essence on the exogenous purchase frequencies and price elasticities of commodity demand. Clements and Nguyen (1980) adopted a static, multiple-good money-in-the-utility-function model and used data for Australia from 1948 to 1977 to conclude that changes in the relative price level have a significant empirical effect on the money demand behavior. Such a finding is, however, left unjustified

inflation. On the one hand, an increase in the relative price raises the effective cost inflation, resulting in a higher interest rate elasticity of money demand. On the other, an asset substitution effect implies the associated increase in the capital cost encourages money holdings, thus dampening the negative effect of anticipated inflation on the demand for money.

We employ data from the Chinese hyperinflation (January 1946 to April 1949) to uncover empirical evidence concerning the importance of the relative price effect on money demand. Among episodes of hyperinflation, the Chinese hyperinflation was the most explosive hyperinflationary experience over a prolonged three-year period in recorded human history. One key advantage of the post-WWII Chinese hyperinflation over the post-WWI German data for the study of the money demand behavior is that the data series contain more observations (40 compared to 30) to apply toward econometric tests. As in Germany, foreign currencies in China were involved in few transactions despite the accelerating inflation over the sample period. Thus, in the benchmark framework, we model the money demand behavior without accounting for international currency substitution. Nevertheless, in order to ensure the robustness of our results, we consider in the empirical implementation the potential for currency substitution by including the "black market" exchange rate in the inflation forecasting equation.

Following Garber (1982), Rogers and Wang (1993) and Tallman and Wang (1995), we measure the relative price variable by the ratio of the wholesale price index to the consumer price index (WPI/CPI).[3] Our empirical results suggest that in addition to the anticipated inflation rate, adverse real disturbances, as indicated by fluctuations in the relative price (or the cost of capital), have significant negative effects on real money balances. The estimates of interactions among

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theoretically. Moreover, both studies are based upon a static framework that ignores any intertemporal dynamics.

[3]   This price index ratio appears a good proxy in their studies of the post-WWI German hyperinflation as well

the anticipated inflation and the relative price variables suggest that there are non-trivial effects on the anticipated inflation effect arising from changes in the relative price. In particular, when the relative price increases, anticipated inflation has a more negative effect on money demand. This reduced sensitivity implies that capital price increases reflect a Tobin asset-substitution – agents demand for capital is only partially captured in the relative price variable. Thus, estimates of the traditional Cagan money demand that ignore the relative price and the interactive effects may under-estimate the welfare costs of hyperinflation.

Our paper complements studies by Abel et al. (1979) and Taylor (1991) on the money demand behavior during the post-WWI German hyperinflation. Abel et al. (1979) suggest that the Cagan model is mis-specified and include other nominal variables such as the forward premium of the nominal exchange rate to improve the estimation. Exchange rate data are observable and available to rational economic agents. If the data contain information in addition to the variables used to predict inflation, then exchange rate data should be part of the instrument set used to form inflation expectations. The exchange rate then affects money demand indirectly. Taylor (1991) revisits this issue by arguing that the Cagan model is mis-specified because it ignores a long-run stable cointegration relation between real balances and rates of inflation. In contrast, our results based on the post-WWII Chinese hyperinflationary experience indicate that *the real disturbances and their nonlinear interactions with anticipated inflation* are responsible for the mis-specification of the Cagan model.

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as of the 1980 hyperinflationary episodes in Israel and several Latin American countries.

The remainder of the paper is organized as follows. Section 2 develops a general cash-in-advance model of money, allowing for explosive money velocity. Section 3 performs steady-state analysis, while section 4 provides empirical evidence using the Chinese hyperinflation data. We then conclude the paper in section 5.

2. A General Cash-in-Advance Model of Money

In this section, we build up a continuous-time, infinite-horizon, perfect-foresight, general cash-in-advance model of money. The framework extends the cash-in-advance models of Lucas (1980), Stockman (1981) and Tallman and Wang (1995) by assuming that all consumption goods and a fraction of capital goods require cash services prior to their transactions. It also generalizes the structure in Wang and Yip (1992) by permitting velocity to vary with anticipated inflation capturing variable transactions frequency that has been observed during episodes of high inflation. Thus, in our model, capital and consumption goods are no longer homogeneous so that the relative price of the capital good in terms of the consumption good can represent real disturbances from changes in the real costs of capital. Also, the incorporation of variable velocity enables us to capture the explosive nature of inflationary spirals.

The general cash-in-advance structure is appropriate for the study the Chinese hyperinflation because China lacked a well-functioning credit market. An interesting phenomenon in the Chinese experience is that people retained money as a medium of exchange during this hyperinflationary period, similar to the experience of Germany following WW I.[4] There was neither a shift to barter nor the use of other means of payment. Campbell and Tullock (1954, p. 244) provide several reasons for this extraordinary acceptance of Chinese Nationalist

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[4] Casella and Feinstein (1990) and Kuczynski (1923) note the continued use of paper currency to support transactions during the post-WW I German hyperinflation. As late as 1923, Kuczynski wrote, "Payments, it must be

Currency as medium of exchange: "Regulations requiring the use of official currencies were strictly enforced .... The governments also controlled the terms of many transactions. Taxes in Free China, except for the agricultural property tax, were paid in legal tender, and goods and services distributed by the government were sold for the official medium. Since foreign trade was negotiated through government exchange banking facilities, the official medium also was required for such transactions."

Let m denote real money balances. Consider a perishable final consumption good c produced by physical capital k through a well-behaved neoclassical production function $y = Af(k)$, where A is a positive technological factor and f is strictly increasing and strictly concave, satisfying the Inada conditions (i.e., $f_k > 0, f_{kk} < 0, \lim_{k \to 0} f_k = \infty$, and $\lim_{k \to \infty} f_k = 0$).

Assume for the sake of simplicity that physical capital does not depreciate. Given the constant rate of population growth n and the anticipated inflation rate π, the representative agent faces a modified Sidrauski (1967)-like budget constraint:

$$c(t) + q(t)\,\dot{k}(t) + \dot{m}(t) = Af(k(t)) - nq(t)k(t) - (\pi + n)\,m(t) + \tau(t), \tag{1}$$

where q denotes the relative price of the capital good in terms of the numeraire (consumption good) and τ denotes real lump-sum money transfer payments. Different from Sidrauski (1967), the real money transfer is assumed lump-sum (rather than proportional) and consumption and capital goods are no longer homogeneous (so that the relative price q enters into the expenditure-side of the budget constraint). Note that capital goods in this model are purchased solely as inputs into the production function.[5]

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remembered, continue to be made in paper marks" (page 761).
    [5]   This limitation of the model hinders our ability to investigate the demand for capital goods that is induced

To motivate the use of money, we construct a general cash-in-advance constraint in which all consumption goods and a fraction (θ) of capital goods have to be purchased via monetary transactions:

$$c(t) + \theta(t)\, q(t)\, \dot{k}(t) \leq v(t)\, m(t). \tag{2}$$

It may be interesting to relate our setup to the conventional models. First, when $\theta(t) = 0$ and $v(t) = 1$ for all $t \geq 0$, equation (2) captures the Lucas (1980) liquidity constraint where only the consumption good is subject to the cash-in-advanced constraint. Second, when $\theta(t) = q(t) = v(t) = 1$ for all $t \geq 0$, equation (2) is equivalent to the Stockman (1981) constraint in which cash is required prior to purchasing any consumption and capital goods. Third, when $\theta(t) = 0$, the cash-in-advance constraint reduces to that in Tallman and Wang (1995). Finally, in contrast to Wang and Yip (1992) who assume $v(t) = 1$ for all $t \geq 0$, we allow for a variable money velocity factor, $v(t)$, to match the transactions interval with the calendar time.[6]

Assume that the representative agent's utility is time-additive with a constant rate of subjective time preferences ρ and with a stationary, well-behaved instantaneous utility function $u(c)$ which is strictly increasing and strictly concave, satisfying the Inada conditions (i.e., $u_c > 0$, $u_{cc} < 0$, $\lim_{c \to 0} u_c = \infty$ and $\lim_{c \to \infty} u_c = 0$). The representative agent's optimization problem is then given by:

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as storage alternatives to paper money. We cannot provide a distinction between capital used for production and capital used for storage alone during the hyperinflation. However, one could imagine that the demand for capital, even if induced by the absence of other viable forms of wealth storage, would involve productive uses of the capital rather than fallow storage.

[6] This velocity factor differs from the standard definition of money velocity, i.e., the ratio of real income ($c + q\dot{k}$) to real money balances (m). In fact, the standard money velocity can be rewritten as $\phi = (c + q\dot{k})/(c + \theta\, q\dot{k})$.

$$\max_{c} \int_0^\infty u(c(t))e^{-\rho t}\, dt$$

$$\text{(PA)}$$

$$\text{s.t.}\,(1)\text{ and }(2).$$

To solve the above optimization problem, we first define a slack variable $z(t) = \dot{k}(t)$. Thus the current-value Hamiltonian can be written as:

$$H(k, m, \lambda_1, \lambda_2, \lambda_3, c, z, t) = u(c)$$

$$+ \lambda_1 \big[Af(k) - nqk - (\pi + n)m - \tau - c - qz \big] \tag{3}$$

$$+ \lambda_2 \big[vm - c - \theta qz \big] + \lambda_3 \big[z \big],$$

where λ_1 and λ_3 are co-state variables associated with constraint (1) and the slack variable identity, $z = \dot{k}$, respectively, and λ_2 is the Lagrangian multiplier associated with constraint (2). Straightforward application of Pontryagin's Maximum Principle yields:

$$u_c - (\lambda_1 + \lambda_2) = 0 \tag{4}$$

$$-q(\lambda_1 + \theta\lambda_2) + \lambda_3 = 0 \tag{5}$$

$$\dot{\lambda}_1 = \rho\lambda_1 + \lambda_1(\pi + n) - \lambda_2 v \tag{6}$$

$$\dot{\lambda}_3 = \rho\lambda_3 - \lambda_1(Af_k - nq) \tag{7}$$

$$\lambda_2\big(vm - c - \theta q\dot{k}\big) = 0 \tag{8}$$

$$\lim_{t\to\infty} \lambda_3(t)k(t)e^{\rho t} = 0 \tag{9}$$

$$\lim_{t\to\infty} \lambda_1(t)m(t)e^{-\rho t} = 0. \tag{10}$$

Equation (4) determines intertemporal consumption efficiency, while (5) pins down the relative price of the capital good to the consumption good. Equations (6) and (7) are Euler's equations, governing the dynamics of real money balances and physical capital. Equation (8) is a Kuhn-Tucker condition indicating whether the cash-in-advance constraint will bind, whereas (9) and (10) are the transversality conditions for capital and real money balances, respectively. Equation system (4) - (10) together with (1) characterize the individual decision policy functions of the representative-agent's optimal control problem (PA).

3.   Comparative-Static Analysis

In the steady state, $\dot{c} = \dot{k} = \dot{m} = 0$ given constant π, v, θ, τ and q. Thus, from (5) and (6), $\dot{\lambda}_1 = \dot{\lambda}_3 = 0$. Notice that under money market equilibrium, $\dot{m} = (\pi + n)m$ and hence

$$c = Af(k) - nqk, \tag{11}$$

which is, in effect, the resource constraint for goods in the steady state. Suppose now that the cash-in-advance constraint is not binding, i.e., $c < vm$. From (8), we have $\lambda_2 = 0$, which in conjunction with (6) imply $\rho + \pi + n = 0$. Yet this latter equality is a knife-edge condition that holds up only for a parameter set of measure zero (and cannot occur in a hyperinflationary economy with positive population growth). Therefore, the cash-in-advance constraint has to be binding in the steady state and so

$$m = \left[Af(k) - nqk\right] / v. \tag{12}$$

That is, real money balances in the steady state is equal to consumption with adjustment of a velocity factor.

Next, substitute (5) and (6) into (7), given $\dot{\lambda}_1 = \dot{\lambda}_3 = 0$, to obtain

$$A f_k(k) = q\left\{n + \rho\left[1 + \theta^* (\rho + n + \pi)\right]\right\} \tag{13}$$

where $\theta^* = \theta / v$. This displays a *modified golden rule* that determines the optimal accumulation of the physical capital stock. In the absence of capital depreciation, the conventional modified golden rule in a Sidrauski-type monetary growth model is $Af_k = n + \rho$, which can be regarded as a special case of ours when $q = 1$ and $\theta = 0$. Thus, our generalized cash-in-advance model adds two additional factors to pin down the optimal capital accumulation: the relative price (q) and the anticipated inflation (via the term associated with non-zero θ). Under the "dynamic efficiency" condition, we have: $A f_k(k) - nq = \rho q[1 + \theta^* (\rho + n + \pi)] > 0$.

Focusing on the equation system (12) - (13), straightforward comparative-static analysis yields:

$$\frac{d\log(m)}{d\pi} = \frac{\theta^* \rho^2 q^2 \left[1 + \theta^*(\rho + n + \pi)\right]}{Af_{kk} y^*} < 0 \tag{14}$$

$$\frac{d\log(m)}{dq} = \frac{\rho q\left[1 + \theta^*(\rho + n + \pi)\right]\left\{n + \rho\left[1 + \theta^*(\rho + n + \pi)\right]\right\}}{Af_{kk} y^*} < 0 \tag{15}$$

where $y^* = Af(k) - nqk$, denoting net output per capita. Therefore, it can be concluded that both the anticipated inflation rate and the relative price of the capital good have adverse effects on money demand. The intuition is straightforward. From (13), an increase in either the anticipated inflation rate or the relative price (of capital to the consumption good) raises the marginal cost of capital, thereby suppressing the steady-state capital accumulation and real transactions. Utilizing

(12) under dynamic efficiency (Af_k-nq > 0), real money balances must then decrease, given a

constant velocity factor in the steady state.[7]

Consider that $\pi > 0$. For the Lucas (1980) case in which $\theta^* = 0$ and v = 1, money

demand and all real variables are independent of the anticipated inflation rate (and so money is

superneutral). In this case, the effect of relative price changes on money demand becomes

smaller. For the Stockman (1981) case in which $\theta^* q = 1$ and v = 1, the magnitude of the relative

price effect (on money demand) is greater than that of the anticipated inflation effect. In general,

the higher the fraction of capital goods that is subject to the cash-in-advance constraint, the larger

are the magnitudes of the anticipated inflation and relative price effects on real money balances.

During hyperinflation, the velocity or transactions frequency factor (v) may tend to be

explosive.[8] In this case, the comparative-static result described in (14) needs to be modified.

Define $\delta(\pi) = \text{dlog(v)}/\text{d}\pi > 0$. We then have:

$$\frac{\text{dlog(m)}}{\text{d}\pi} = -[\,\delta(\pi) + \phi(\pi,\ q)] \tag{16}$$

where

$$\phi(\pi,\ q) = -\frac{\theta^* \rho^2 q^2 \left[1 + \theta^*(\rho + \pi + n)\right]}{Af_{kk}y^*} > 0,\ \text{with}\ \frac{\partial\phi}{\partial\pi} > 0,\ \frac{\partial\phi}{\partial q} > 0.$$

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[7]   Tallman and Wang (1995) interpret shocks to the relative price ratio as a proxy for real price increases. In contrast, the relative price variable in this paper is a cost of capital proxy and is used for comparative static results. We do not model the dynamic evolution of the relative price variable.

[8]   See Cagan (1956) for further elaboration on the acceleration of inflation at an ever increasing speed.

Thus, it is clear that while the effect of the relative price or cost of capital on money demand remains negative, the variable velocity factor magnifies the adverse effect of anticipated inflation.

It may be interesting to elaborate further on the model implications based on two benchmark cases. First, consider the case that log(v) and π increase at the same speed (so δ becomes a constant). From (16), we note that the coefficient (in absolute value) on the inflation term in the money demand equation depends positively on the inflation rate. Hence, there is an acceleration of the negative effect of inflation on the demand for money as the rate of inflation becomes higher. Next, we study the case that v and π increase at the same speed. In this case, the inflation cost is fully absorbed by the changes in transactions frequencies and hence real money holdings become independent of the inflation rate, as it increases unboundedly. However, it can be shown from (15) that when π approaches infinity,

$$\frac{d\log(m)}{dq} = \frac{\rho^2 q(1+\theta)\left[n+\rho(1+\theta)\right]}{Af_{kk}y^*} < 0.$$

Thus, the effect of relative prices on money demand is larger in magnitude than in the previous case.

In general, the results in (15) and (16) are rather robust even with a variable velocity factor depending upon the rate of inflation. It is also interesting to see from these two equations that in addition to the level of inflation and the level of the relative price, there are other interactive terms that also affect money demand. In the first order sense, these interactive terms include πq, πq^2, and $\pi^2 q^2$. Our theory concludes that money demand depends negatively on both the anticipated inflation rate and the relative price level. The effect of the relative price on the response of money demand to anticipated inflation is however ambiguous. On the one hand,

an increase in the relative price accelerates the effective cost of inflation, resulting in a higher interest rate elasticity of money demand. On the other, an asset substitution effect implies the associated increase in the capital cost encourages money holdings, thus dampening the negative effect of anticipated inflation on the demand for money. Overlooking the real disturbances represented by changes in the relative price and these interactive terms may mismeasure the effect of inflation on money demand, leading to biased welfare evaluations.

Since hyperinflation is a short-term phenomenon, it is important to examine the model's dynamic properties along a transition path, in particular, the dynamics of a generalized cash-in-advance model has not yet been studied in the literature. Since there are two state, two co-state and two control variables in the optimization problem, it is necessary to transform the system into a tractable framework. To do so, we use the monetary equilibrium relationship, $\dot{m} = \tau - (\pi + n)m$, to simplify (1) as:

$$\dot{k} = (1/q)[Af(k) - c] - nk \tag{17}$$

Next, we define the shadow price of capital as $\gamma = \lambda_3/\lambda_1$. From (5), we can derive: $\lambda_2/\lambda_1 = (1/\theta)(\gamma/q - 1)$, which can be substituted into (6) and (7) to obtain:

$$\dot{\gamma} = \gamma[(v/\theta)(\gamma/q - 1) - (\pi + n)] - (Af_k - nq) \tag{18}$$

Totally differentiating (4) and (5) and utilizing the expression of λ_2/λ_1 above as well as equations (6) and (18), we can produce the dynamics of consumption:

$$\dot{c} = -\sigma c \left(\psi \left\{ \gamma[(v/\theta)(\gamma/q - 1) - (\pi + n)] - (Af_k - nq) \right\} + (\rho + \pi + n) - (v/\theta)(\gamma/q - 1) \right) \tag{19}$$

where $\sigma = \dfrac{-u_c}{cu_{cc}} > 0$ is the elasticity of intertemporal substitution and $\psi = \dfrac{1/(\theta q)}{1 + (1/\theta)(\gamma/q - 1)} > 0$.

Equations (17)-(19) form the dynamical system of (k, γ, c). Totally differentiating the system and evaluating it around the steady state $(\bar{k}, \bar{\gamma}, \bar{c})$ yield:

$$
\begin{bmatrix} \dot{k} \\ \dot{\gamma} \\ \dot{c} \end{bmatrix} = \begin{bmatrix} \rho[1+(\theta/v)(\rho+n+\pi)] & 0 & -1/q \\ -Af_{kk} & \rho+(v/\theta)(\gamma/q) & 0 \\ \sigma c\psi Af_{kk} & -\sigma c\psi[\rho+(v/\theta)(\gamma/q)]+\sigma c/(\theta q) & 0 \end{bmatrix} \begin{bmatrix} k-\bar{k} \\ \gamma-\bar{\gamma} \\ c-\bar{c} \end{bmatrix} \quad (20)
$$

where in deriving the Jacobean matrix (denoted J), we have used the steady-state relationships

(13) and $(v/\theta)(\gamma/q - 1) = \rho + \pi + n$. Denote the trace and the determinant of J as Tr(J) and Det(J),

respectively. It is clear that the Tr(J) = $\rho[2+(\theta/v)(\rho+\pi+n)] + (v/\theta)(\gamma/q) > 0$ and Det(J) =

$\sigma cAf_{kk}/(\theta q^2) < 0$. This implies that the system has one stabilizing root and two destabilizing

roots. Since there are two jumping variables (γ and c), the dynamical system must be saddle-

path stable. Therefore, the transition path is uniquely determined and, except for the

instantaneous jump, all endogenous variables converge to the steady state monotonically. This

enables us to focus on steady-state analysis without loss of generality with regard to short-run

dynamics.

4.   Empirical Evidence

The Chinese hyperinflation data from 1946:01 to 1949:04 (monthly) provides an

opportunity to investigate the theoretical predictions that nonlinear terms (of relative price and

anticipated inflation as well as interactions) can better explain the behavior of money demand.

We employ the wholesale price index (WPI) as the measure of the price level because it

represents more accurately the costs faced by businesses. The cost of living index (CLI) is the

measure of consumption goods prices. We take the ratio WPI/CLI as the relative price of capital,

following Garber (1982), Rogers and Wang (1993), and Tallman and Wang (1995).[9] The WPI

consists of 50 commodities including foodstuffs, textile, metals, fuels, and construction

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[9]   Garber (1982) found that hyperinflation produced a bias in favor of investment goods over consumption

materials. The CLI consists of four categories: food, clothing, housing, and miscellaneous items.

Included in the WPI and the CLI are both investment and consumption goods, although the WPI certainly contains relatively more investment goods than the CLI. Therefore, the relative price proxy (WPI/CLI) is not a precise measure. This figure understates the price of investment goods, an undesirable characteristic, but data on investment goods prices are not generally available. Clearly, the WPI and the CLI as the prices of baskets of goods that can be regarded as two "aggregators" of investment and consumption goods, where the WPI aggregator is "investment good intensive" and the CLI aggregator is "consumption good intensive." The property of the Stolper-Samuelson Theorem can then be applied: an increase in the WPI/CLI ratio means a more-than-proportional increase in the investment goods price and a decrease in the consumption goods price. Thus, changes in relative prices should be a monotone function of the proxy measure, and our analysis should be valid as long as we recognize that the magnitude of the relative price proxy may be downward biased.

The money supply is measured as billions of Chinese National Currency (CNC), in yuan. To maintain consistency of the series, we adjust the money supply to account for the revaluation of the Chinese currency following the failed monetary reform in August 1948. We also use the Chinese yuan/US dollar exchange rate (black market rate) to indicate expectations of the value of the domestic currency from sources external to the country. In our application, a larger number indicates depreciation of the currency, and hence indicates the anticipation of further inflation in the future. To accommodate the concept of money demand as a flow variable, we take the geometric average of real money balances (measured by the money supply deflated by the WPI) calibrated to the middle of the month.

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goods in Germany.

The degree of the hyperinflation was so severe that if one makes an index with 1936 = 100, then both the wholesale and the consumer price indexes end up being fifteen-digit numbers by 1949. During a more focused period, the level of the money supply increased by more than 600 times from its initial value in January 1946 to August 1948. Following the monetary reform in August 1948, the money supply grew explosively again. From August 1948 until April 1949, the money supply increased by more than 9,400 times. Nevertheless, the money growth rate is far less than the resulting inflation rate. Separately, in Figure 1 we present evidence that the ratio of the WPI to the CLI substantially increased during the hyperinflationary period. The ratio increased from below 1 prior to 1947 to about 1.5 in 1948; the relative price then shot up to over 2 in late 1948. We use two equations to study money demand behavior during the Chinese hyperinflation. First, we specify a model of inflation expectations to isolate an explicit proxy measure for "anticipated inflation" to use in the money demand function. The inflation expectations model is a function of lagged inflation, current and lagged money supply growth, and current and lagged black market exchange rates. The depreciation of the exchange rate may not be a driving force of inflation. However, it may be used as an indicator of domestic inflation expectations held by foreign exchange market participants.

$$\pi_t = \alpha_0 + \sum_{i=1}^{n1}\alpha_{1,i}\pi_{t-i} + \sum_{i=1}^{n2}\alpha_{2,i}\mu_{t-i} + \sum_{i=0}^{n3}\alpha_{3,i}\ln(s_{t-i}) + \varepsilon_t \qquad (21)$$

where π is the inflation rate measured by the rate of change in the WPI, μ is the mid-month money growth rate, and s is the spot "black market" exchange rate.[10]

In the benchmark case of an inflation expectations model as described above, we do not include contemporaneous values of the money supply growth rates in the inflation forecasting

equation. If the money supply process were exogenous, then the monetary authority by assumption does not respond to the budget concerns of the fiscal authority. In practice, however, the monetary authority often responds to high inflation and low tax revenue by increasing the money supply growth rate, thus causing a debt-inflation spiral (Tanzi 1977). Our current setup can explicitly account for this without altering qualitatively the money demand specification; yet, we leave it out for the sake of simplicity. To avoid the potential problem associated with the endogeneity of money supply creation, however, we use only lagged values of the money supply growth rates in the inflation forecasting equation (although adding contemporaneous money growth into the regression does not alter the main implications of the results).[11]

For the inflation expectations specification, we employed the Schwartz Information Criteria (SIC) to choose the lag lengths appropriate for each of these variables, with the maximum lag set at 6. The SIC results suggest the following specification for the inflation forecasting equation: one lag of the inflation rate, the current value and two lagged values of the money growth rate, and the current log-level of exchange rate. Then we use this specification as the inflation rate forecasting equation to generate a proxy measure for anticipated inflation for the money demand equation. We note that we have considered alternative specifications of the inflation forecasting equation: (i) incorporating contemporaneous money supply creation and (ii) specifying the current exchange rate in logged differences. As can be seen in the Appendix, these alternatives have little effect on the estimation results.[12] In the benchmark expected

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[10]   The black market exchange rate data were from banks in the Shanghai area.
[11]   In fact, the inclusion of contemporaneous values of money growth in the inflation forecasting equation may also create problems due to simultaneity when the inflation forecast enters as an explanatory variable for real money demand.
[12]   In the Appendix, Table 1A presents regression results that obtain if contemporaneous money growth were included among the regressors in the inflation forecasting equation, whereas Table 1B displays those with the

inflation estimation reported in Table 1, the spot black market exchange rate serves as an important explanatory variable in predicting inflation rate movements. The estimated parameters include negative coefficients on inflation and on the sum weights of money growth. These unusual coefficient values in the inflation forecasting equation arise from our use of the log-level of the black market exchange rate. In this instance, the exchange rate picks up forward-looking depreciation of the yuan, swamping the contribution of the lagged variables for inflation forecasting.[13]

In contrast with Abel et al. (1979) on the German hyperinflation case, we include the exchange rate variable in the inflation expectations equation.[14] The inclusion of the black market exchange rate in the formation of inflation expectations accounts for any possible currency substitution in transactions during the Chinese hyperinflation. Thus, the effect of domestic currency depreciation has an indirect negative effect on money demand via anticipated inflation. Also in contrast with the hyperinflation study of six European countries by Taylor (1991), Tallman and Wang (1995) find no clear-cut evidence of a long-run, stable linear relationship between real money balances (in logs) and inflation rates in the case of Chinese hyperinflation. Rather, our theoretical and the accompanying econometric model suggest that the real

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current exchange rate in logged differences. We have also considered fewer (one) and more (three) lagged values of the money growth rate and found virtually the same results, which are thus omitted in the paper.

[13] In alternative specifications, specifications using first-difference in the log of the exchange rate (e.g., Appendix Table 1B) captures the forward-looking aspect of the level, and yet generates more interpretable positive coefficients on lagged inflation and lagged money growth. Also, should contemporary money growth be included, its estimated effect is certainly positive (see Appendix Table 1A). Further, more standard positive coefficients on money and inflation arise in specifications that eliminate the exchange rate variable from the regression, but the explanatory power of the regression is notably diminished.

[14] Frenkel (1977) used the foward premium of the nominal exchange rate in forecasting inflation during the German hyperinflation. There was no forward market in China during our sample period so that such a variable is unavailable.

disturbances and their nonlinear interactions with anticipated inflation are likely to be

responsible for any mis-specification of the Cagan model.

The second equation is the money demand equation, and we examine a selection of

specifications motivated by the theoretical results and contrast them with the standard Cagan

model.

$$\log(m)_t = \beta_0 + \beta_1 \pi_t^e + e_t \tag{22a}$$

$$\log(m)_t = \beta_0 + \beta_1 \pi_t^e + \beta_2 q_t + e_t \tag{22b}$$

$$\log(m)_t = \beta_0 + \beta_1 \pi_t^e + \beta_2 q_t^2 + \beta_3 \pi_t^e q_t + e_t \tag{22c}$$

$$\log(m)_t = \beta_0 + \beta_1 \pi_t^e + \beta_2 q_t^2 + \beta_3 \pi_t^e q_t^2 + e_t \tag{22d}$$

$$\log(m)_t = \beta_0 + \beta_1 \pi_t^e + \beta_2 q_t^2 + \beta_3 (\pi_t^e q_t)^2 + e_t \tag{22e}$$

here m is M/P, M is an index of the quantity of notes issued by the Bank of China, P is the

wholesale price index, π^e is the estimated "expected" rate of inflation (wholesale price

inflation), and q is the relative price measure (WPI/CLI). In the absence of the data on the GDP

deflator, WPI could serve as a good proxy. [15] However, to show the robustness of our main

findings, we provide in the Appendix estimations based on an alternative measure of P - a simple

average of the WPI and the CLI.[16]

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[15]   For example, see Frenkel's (1977) study on the Germany hyperinflation.
[16]   The average price index normalizes each data series as 100 in January of 1946. Then, a new index is
created as the simple average of the two series. Results performed with the index as the geometric average of the
series were virtually unchanged. The results are provided in Tables 1C and 2C. If we use the CLI as the price index
for inflation, the expected inflation rate and the nonlinear terms in equations (22c, d, and e) remain significant. We
note that the only result **not** robust to changing from the WPI to the CLI as the deflator is the negative and
significant impact of the relative price measure. We have also considered the relative price ratio transformed as
natural logarithm of the ratio. Since the results are virtually unchanged, they are omitted in the paper.

Equation (22a) is the standard Cagan hyperinflation money demand; (22b) includes the relative price as an additional explanatory variable. Equations (22c, d, and e) introduce interactive terms between the relative price and expected inflation as implied by the theoretical model. Based on the Fisher equation, the direct measure of the interest rate semi-elasticity of money demand is β_1. In the equations with nonlinear interactive terms, this interest semi-elasticity is more complicated as described below. We assume that the money supply growth rate and the real cost of capital are exogenous to the system. The money demand model uses the inflation forecast as a proxy for anticipated inflation. There is error implicit in estimating expected inflation in a separate equation when it is used as an explanatory variable in the money demand equation. We use instrumental variables estimation to account for this error and to generate results robust to the generated regressor problem.

In Tables 1 and 2, we report the results from jointly estimating equation (21) combined with a selected equation from (22a-e) over the period from January 1946 to April 1949.[17] The results suggest that regressions including real disturbances measured by the relative prices of capital outperform the Cagan model. Both anticipated inflation and the relative price of capital have the correct negative sign as predicted by the theoretical model. The models with nonlinear interactive terms between the relative price measure and anticipated inflation explain the variation of money demand more effectively than those excluding them. The estimated semi-elasticity of money demand to the interest rate in the Cagan model is estimated to be approximately -1.2; comparable estimates for the German hyperinflation range from -.4 to -3.3 [see Frenkel (1977), Abel et al. (1979), and Taylor (1991)]. By including the relative price variable as in the specification (22b), the semi-elasticity estimate drops (in absolute value)

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[17]   January 1946 to March 1946 were treated as pre-sample values and provided the initial two lags in the

slightly to -1.1 reducing about .1 or by approximately one standard error of the coefficient

estimate. For the specifications that include nonlinear interaction terms, the direct measure of

the semi-elasticity ranges from -1.5 to -2.1. The magnitude of this semi-elasticity is positively

related to the Harberger triangle measure of the welfare costs of inflation. Hence, our results

suggest that the welfare costs of the Chinese hyperinflation appear greater once the nonlinear

interaction terms are included. Among the three specifications with nonlinear terms, the general

indicators of fit are comparable.[18]

    To check the robustness of our findings, we also estimated the money demand equations

using expected inflation and the interactive terms generated from a two-step instrumental

variables procedure. In the first step, expected inflation was generated "out-of-sample" from the

baseline expected inflation specification. The generated inflation forecast was then used to

create the interactive terms and as a regressor in the money demand equation using the same

selection of instruments as in the simultaneous procedure. The estimation results shown in

Appendix Table 2A show that virtually all the parameter estimates and statistics are robust to this

alternative inflation forecasting procedure.[19]

    The regression coefficient estimates for the nonlinear terms are not intuitive in their raw

form. The coefficients from non-linear terms affect the implied semi-elasticities of money

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differenced series.

[18]   In the Appendix, Table 2D displays the demand for money estimates that would obtain if the models were estimated over the shortened sample, using the same specification of the inflation forecasting equation as in the paper. These estimates are included only for comparison. We note that the results (and the related inferences) from the base specification using the WPI are robust to ending the estimation sample at August 1948.

[19]   We note that a two-step OLS procedure is inefficient (and perhaps inconsistent) relative to the simultaneous estimation of the two equations due to the use of a "generated regressor" (see Pagan 1984a). As a result, we estimate the coefficients using an instrumental variables procedure as suggested. The two step procedure has the appeal that forecasts of inflation are generated with only information that could have been available to market participants.

demand to both inflation expectations and relative prices from the regressions. Below, we

describe the measures of semi-elasticities as implied in the nonlinear specifications (22c to 22e):

$$\frac{\text{dlog(m)}_t}{\text{d}\pi_t} = \beta_1 + \beta_3 q_t, \quad \frac{\text{dlog(m)}_t}{\text{d}q_t} = 2\beta_2 + \beta_3 \pi_t^e \tag{23a}$$

$$\frac{\text{dlog(m)}_t}{\text{d}\pi_t} = \beta_1 + \beta_3 q_t^2, \quad \frac{\text{dlog(m)}_t}{\text{d}q_t} = 2(\beta_2 + \beta_3 \pi_t^e) q_t \tag{23b}$$

$$\frac{\text{dlog(m)}_t}{\text{d}\pi_t} = \beta_1 + 2\beta_3 q_t^2 \pi_t^e, \quad \frac{\text{dlog(m)}_t}{\text{d}q_t} = 2[\beta_2 + \beta_3 (\pi_t^e)^2] q_t \tag{23c}$$

In Figure 2 we display the time-series pattern of the semi-elasticity measures that clearly depend

on the time series of anticipated inflation and of the relative price. As shown, this Figure is a 6

panel graph that compares the implied semi-elasticity measures across the specifications. On the

basis of theory, we anticipate that both estimates should be negative throughout the sample

period. Thus, we select model (22d) as the specification that is most consistent with our priors

(middle panels). The effect of relative prices on money demand is generally constant up to mid-

1948. Then, as inflation accelerates, money demand responds less to real disturbances, thus

supporting the assertion by Cagan (1956) that real disturbances are less influential when inflation

accelerates very explosively. The time-varying effect of anticipated inflation diminishes

relatively steadily until mid-1948, when it increases abruptly. After the monetary reform in

August 1948, the response of money demand to anticipated inflation drops from -1.1 to

approximately 0.0, indicating partial success of the currency reform. However, as the Reform

appeared more futile, the money demand response to anticipated inflation increased dramatically

to reach less than -1.5 by the end of our sample.

As documented by Campbell and Tullock (1954), there were few alternative assets to holding Chinese currency. The theoretical model suggests that an increase in anticipated inflation raises the effective cost of capital, $\rho[1+\theta^*(\rho+n+\pi)]q$. Increasing this cost will reduce capital accumulation and the marginal benefit of holding money. The reduction in capital through asset substitution will encourage real money balance holdings in a second-order fashion; the lower marginal benefit of holding money will discourage holding more money balances. The estimated coefficients of the interaction terms are all positive, suggesting that the second order asset substitution effects dominate the effect via the indirect marginal benefit mentioned above. In addition, the lack of viable, alternative stores of wealth in China may have added to the demand for capital goods as purely storage capital, motivated purely by the hyperinflation. In essence, it was an extreme example of a Tobin effect.

5. Concluding Remarks

This paper re-examines the importance of relative price fluctuations as an explanatory variable for money demand during hyperinflations. The theoretical model derived in this paper indicates that there are nonlinear interactive terms in relative prices and anticipated inflation that may also impact money demand in a more general setting.

We investigate this implication empirically and find that the relative price term as well as the relevant nonlinear interactive terms are important explanatory variables for money demand during the Chinese hyperinflation. Hence, this paper points out two specification problems that affect the Cagan model of hyperinflation: (i) the omission of real disturbances and, (ii) the interaction terms between anticipated inflation and proxies of real activity. The consequences of this mis-specification will understate the true welfare costs of hyperinflation.

For future work, it may be of interest to apply our theoretical and empirical framework to other hyperinflationary experiences, such as the post-WWI German hyperinflation and the 1980's episodes in Israel and several Latin American countries. Such exercises are valuable in two aspects. On the one hand, one may examine the robustness of the inclusion of relative price variables and nonlinear interactive terms in explaining the money demand behavior during hyperinflationary episodes. On the other, one may compare and contrast the interactive effects between the real and monetary sectors, which may help understand the transmission mechanism of monetary disturbances in the absence of a credible central bank.

Appendix Table 1A: Inflation Forecasting Equation (Contemporaneous Money)

Time	Constant	Π	MG	EG
	-0.765			
	(-3.09)			
t			1.40	0.101
			(4.97)	(3.16)
t-1		-0.494	-2.730	
		(-3.55)	(-5.86)	
t-2			1.794	
			(3.99)	

R² = 0.835
s.e. = 0.285
DW = 1.74

Notes: As in Table 1 except for the inclusion of the contemporaneous value of money supply growth.

APPENDIX Table 2A: Demand for Money in China: September 1946 - April 1949 *

(OLS -- Expected inflation equation is estimated with an increasing sample, and expected inflation is "out-of-sample" forecast)

Eqn. No.	Constant	Π_t^e	Q_t	$Q_t * \Pi_t^e$	Q_t^2	$Q_t^2 * \Pi_t^e$	$(Q_t * \Pi_t^e)^2$	$\bar{R}^2$	s.e.	DW
(18a)	-0.670 (-7.74)	-1.81 (-4.73)						.623	.579	1.80
(18b)	-0.528 (-0.78)	-1.75 (-3.78)	0.136 (0.22)					.612	.588	1.75
(18c)	0.335 (1.02)	-3.91 (-6.51)		2.114 (3.31)	-0.840 (-3.07)			.726	.494	1.41
(18d)	0.27 (0.94)	-2.60 (-5.65)			-0.741 (-3.36)	0.666 (3.78)		.709	.509	1.42
(18e)	-0.066 (-0.26)	-2.28 (-4.76)			-0.392 (-1.78)		0.280 (3.86)	.691	.524	1.59

Notes: As in Table 2. We have fewer observations to have sufficient degrees of freedom for out-of-sample forecasts.
Coefficient estimates: two-stage IV procedure – 1) generate inflation forecasts "out-of-sample" (baseline specification (i.e., lagged money growth, log exchange rate). Use generated series to construct the non-linear variables, and also as regressor in above results.

Appendix Table 1B -- Differenced Logarithm of Exchange Rate

Inflation Forecasting Equation

Time	Constant	Π	MG	EG
	-.06 (-.54)			
t				.45 (2.8)
t-1		.07 (.45)	-.43 (-.8)	
t-2			1.4 (2.34)	

R² = .63
s.e. = .43
DW = 2.14

Notes: As in Table 1 except that EG is the differenced logarithm in the dollar-CNC exchange rate.

Appendix Table 2B -- Differenced Logarithm of Exchange Rate

Demand for Money in China: January 1946 - April 1949

Eqn. No.	Constant	Π_t^e	Q_t	$Q_t * \Pi_t^e$	Q_t^2	$Q_t^2 * \Pi_t^e$	$(Q_t * \Pi_t^e)^2$	$\bar{R}^2$	s.e.	DW
(18a)	-.72 (-8.5)	-1.23 (-11.9)						.8	.406	1.66
(18b)	-.11 (-.44)	-1.12 (-10.8)	-.55 (-2.5)					.83	.371	1.42
(18c)	-.1 (-.6)	-1.98 (-8.1)		.8 (3.8)	-.52 (-4.7)			.87	.33	1.28
(18d)	-.05 (-.3)	-1.6 (-10.3)			-.53 (-4.8)	.33 (3.9)		.87	.328	1.3
(18e)	-.13 (-1.1)	-1.68 (-12.2)			-.38 (-5.2)		.15 (5.3)	.894	.296	1.66

Notes: As in Table 2.

Appendix 1C – Price Index Created as Simple Average of WPI, CLI Inflation
Full Sample -- Inflation Forecasting Equation

Time	Constant	Π	MG	EG
	-1.3 (-3.9)			
t				.17 (3.9)
t-1		-.32 (-1.5)	-1.17 (-2.00)	
t-2			.71 (1.1)	

R^2 = .67
s.e. = .428
DW = 1.4

Notes: As in Tables 1 except the measure of the price index. The average price index normalizes each data series as 100 in January of 1946. Then, a new index is created as the simple average of the two series. Results performed with the index as the geometric average of the series were virtually unchanged.

Appendix Table 2C -- Price Index Created as Average of WPI and CLI

Demand for Money in China: January 1946 - April 1949

Eqn. No.	Constant	Π_t^e	Q_t	$Q_t * \Pi_t^e$	Q_t^2	$Q_t^2 * \Pi_t^e$	$(Q_t * \Pi_t^e)^2$	$\bar{R}^2$	s.e.	DW
(18a)	6.23 (87.5)	-1.13 (-13.8)						.85	.343	1.72
(18b)	6.58 (29.2)	1.08 (-12.8)	-.32 (-1.7)					.86	.327	1.51
(18c)	6.64 (50.0)	-1.64 (-8.3)		.56 (3.11)	-.34 (-3.55)			.88	.299	1.26
(18d)	6.65 (49.3)	-1.37 (-11.2)			-.35 (-3.58)	.23 (3.14)		.89	.297	1.26
(18e)	6.62 (58.6)	-1.46 (-12.1)			-.26 (-3.74)			.90	.276	1.48

Notes: As in Table 2. The average price index normalizes each data series as 100 in January of 1946. Then, a new index is created as the simple average of the two series. Results performed with the index as the geometric average of the series were virtually unchanged.

Appendix Table 2D -- Shortened Sample
Demand for Money in China: January 1946 – August 1948

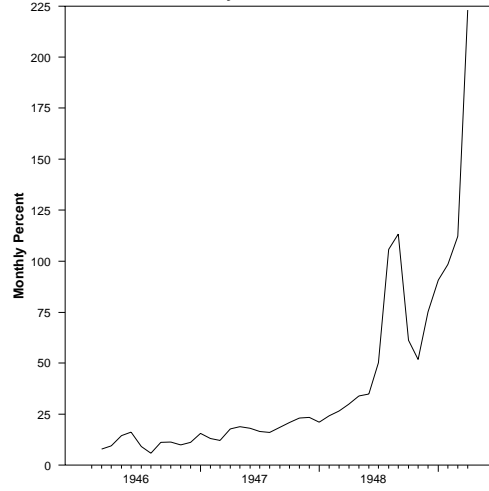| Eqn. No.	Constant	Π_t^e	Q_t	$Q_t * \Pi_t^e$	Q_t^2	$Q_t^2 * \Pi_t^e$	$(Q_t * \Pi_t^e)^2$	$\overline{R}^2$	s.e.	DW
(18a)	-.64 (-8.8)	-1.56 (-7.6)						.68	.25	0.94
(18b)	.58 (2.8)	-.83 (-4.7)	-1.27 (-6.2)					.87	.16	1.76
(18c)	.02 (.15)	-1.9 (-2.2)		.88 (1.3)	-.67 (-4.7)			.85	.17	1.74
(18d)	.03 (.21)	-1.42 (-3.1)			-.67 (-5.2)	.37 (1.5)		.85	.17	1.7
(18e)	-.07 (-.54)	-1.1 (-3.56)			-.58 (-5.7)		.16 (1.2)	.85	.17	1.74

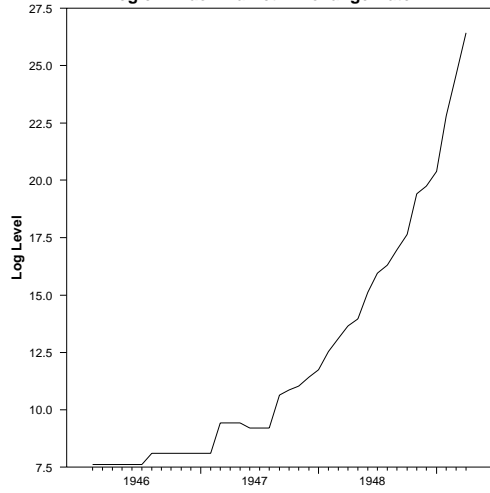Notes: As in Table 2.

Appendix – Data Graphics

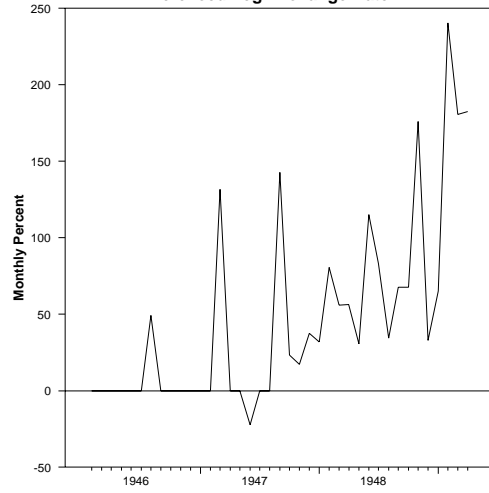**Inflation Measured by Wholesale Price versus Cost of Living Indexes**
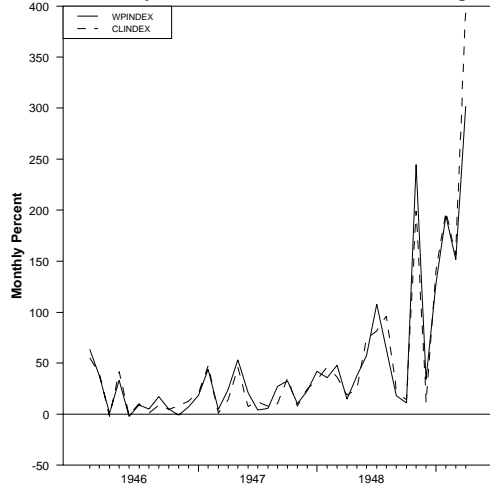
Money Growth Rate

Log of "Black Market" Exchange Rate

Differenced Log Exchange Rate

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Table 1: Inflation Forecasting Equation

Time	Constant	Π	MG	EG
	-1.29 (-3.67)			
t				0.169 (3.49)
t-1		-0.354 (-1.59)	-1.483 (-2.81)	
t-2			0.954 (1.61)	

$\bar{R}^2$ = 0.709
s.e. = 0.379
DW = 1.50

Notes: $\bar{R}^2$ is the adjusted R^2 (coefficient of determination), s.e. is the standard error of the regresion, and t-values are reported in parentheses. Π is the inflation rate, MG is the money growth rate, and EG is the natural logarithm of the dollar-CNC exchange rate. Note that t-1 (leftmost column) is lagged one period relative to the dependent variable. The DW statistic is biased toward non-rejection of the null hypothesis of no autocorrelation of the errors when a lagged dependent variable is present. Exclusion tests as suggested by Pagan (1984b) indicated no serious autocorrelation problem.

Table 2: Demand for Money in China: January 1946 - April 1949

Eqn. No.	Constant	Π_t^e	Q_t	$Q_t * \Pi_t^e$	Q_t^2	$Q_t^2 * \Pi_t^e$	$(Q_t * \Pi_t^e)^2$	$\bar{R}^2$	s.e.	DW
(18a)	-0.720 (-8.38)	-1.24 (-12.0)						.801	.407	1.69
(18b)	-0.194 (-0.72)	-1.13 (-10.4)	-0.483 (-2.04)					.834	.371	1.46
(18c)	-0.104 (-0.67)	-2.15 (-7.82)		0.920 (4.05)	-0.506 (-4.47)			.858	.343	1.47
(18d)	-0.08 (-0.51)	-1.69 (-9.83)			-0.510 (-4.53)	0.367 (4.07)		.864	.336	1.45
(18e)	-0.190 (-1.61)	-1.510 (-11.8)			-0.330 (-4.43)		.152 (5.14)	.893	.298	1.74

Notes: In addition to notes to Table 1, Q is the relative price measured by the ratio of WPI to CPI. Π_t^e is the estimated measure of anticipated inflation. The dependent variable is the natural logarithm of real cash balances, log(M/P), with the WPI used as the price deflator (P). The two stage least squares estimation procedure was used to estimate jointly the money demand and the inflation expectations equation. The instruments are lagged values of the dependent and independent variables, a constant, and lagged inflation and money growth rates.
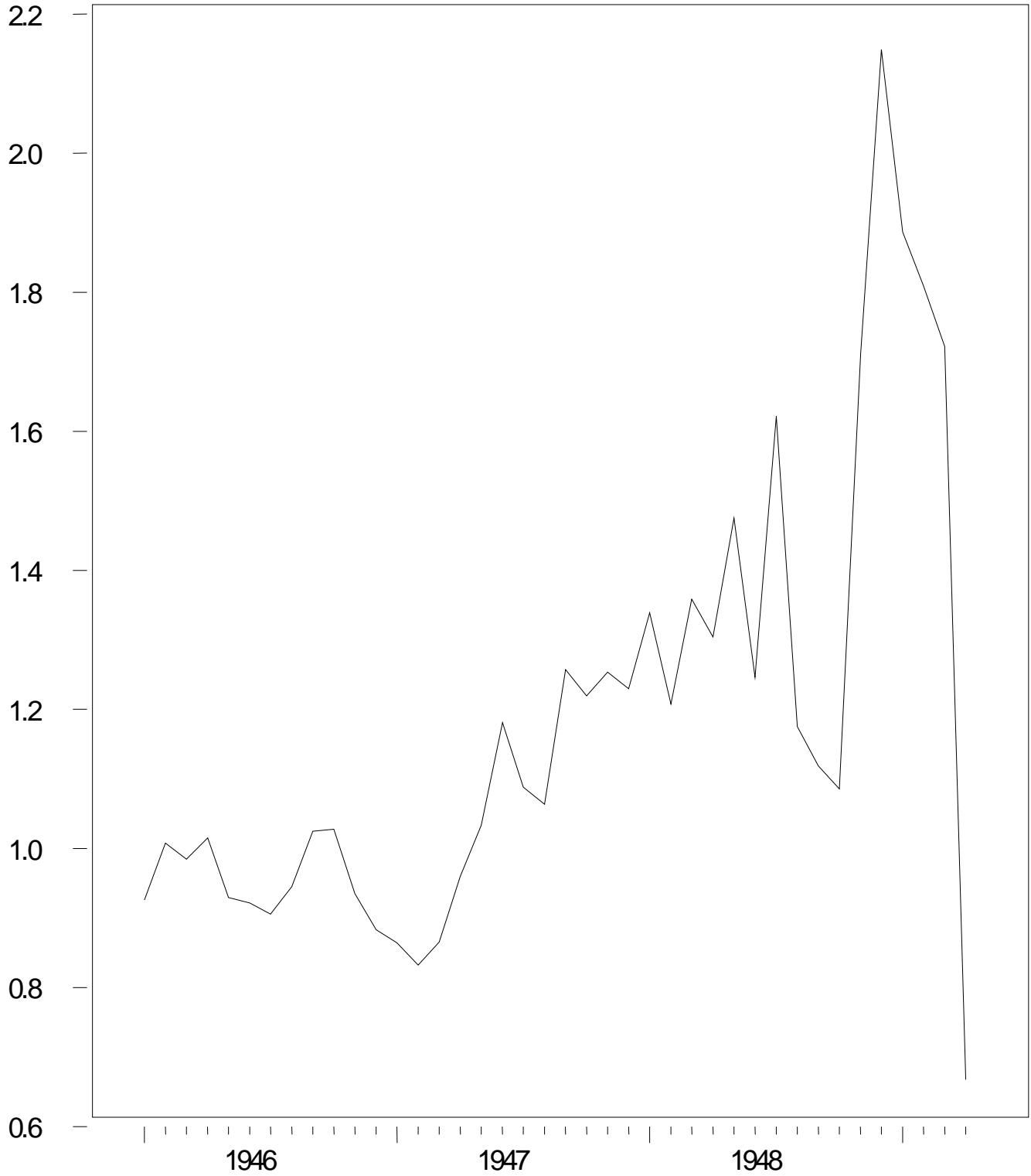
Figure 1: Relative Price in China, 1946:01-49:04

Figure 2: Time-Varying Coefficients on Inflation and Relative Price

$$\pi_t^e \qquad\qquad Q_t$$