The Monetary Dynamics of Hyperinflation Reconsidered

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I will show that, contrary to what profession has believed since Cagan (1956), there is no Laffer curve for seignorage …

True relationship between money growth and seignorage is on the left …

This has material implications along multiple dimensions …

Result was implicit in Sargent and Wallace (IER, 1973), but they did not realize it …

Laffer curve is figment of estimating money demand model that is, in fact, clearly rejected by data …
What are hyperinflations?

Brief episodes characterized by extraordinary increases in money growth and therefore inflation …

E.g., between July 1945 and August 1946, Hungary experienced highest hyperinflation ever: in 13 months prices increased by factor of $3 \times 10^{25}$ …

What are causes of hyperinflations? From Bresciani-Turroni’s (1937) book on Weimar Republic’s episode, to Sargent’s (1982) ‘The Ends of Four Big Inflations’: enormous budget deficits which are financed by printing money, i.e. via the inflation tax, also known as seignorage …

Such enormous deficits are typically product of revolutions (e.g., French Revolution), wars (e.g., WWI, WWII), or civil wars …
Since Cagan (1956), literature on hyperinflations has been dominated by view featuring two main elements:

(1) relationship between money growth and seignorage is hump-shaped—i.e., it follows Laffer curve (below);
(2) historically, governments have inflated in excess of revenue-maximizing rate, i.e., they have been on ‘wrong side’ of Laffer curve (i.e., in point B) …

This view can be found in Sargent and Wallace (IER, 1973), Sargent (IER, 1977), Salemi and Sargent (IER, 1979), Christiano (IER, 1987), etc. etc. …

… and in all Ph.D. textbooks, from Blanchard and Fischer (1990) to Walsh (2017) …

How did Cagan, Sargent, etc. identify Laffer curve for seignorage?
They all estimated Cagan’s ‘semi-log’ money demand:

\[
\ln \left( \frac{M_t}{P_t Y_t} \right) = \beta - \alpha \pi_t^e
\]

linking logarithm of money balances over nominal GDP to level of opportunity cost of money—here, expected inflation …

Based on estimated money demand curve, relationship between money growth and seigniorage can trivially be computed …

Entire literature is based on Cagan’s ‘semi-log’ …

However, e.g., Lucas (Econometrica, 2000, footnote 4): Laffer curve for seigniorage is mathematical property of semi-log …

Therefore, when you estimate semi-log, you impose Laffer curve upon the data: this is what literature has been doing since 1956 …

Benati, Lucas, Nicolini, and Weber (JME, 2021): for 44 countries since WWI most plausible money demand specification is not Cagan’s, but rather Meltzer’s (JPE, 1963) ‘log-log’ …
\[
\ln \left( \frac{M_t}{P_t Y_t} \right) = \phi - \gamma \ln(\pi_t^e) 
\]

… which makes logarithm of money balances over nominal GDP depend on logarithm of opportunity cost of money …

In that paper we exclusively focused on very long samples …

In the present work I show that the data’s preference for the ‘log-log’ is especially clear for hyperinflations …

Does this have implications for our purposes?

Yes: log-log implies uniformly positive relationship between money growth and seignorage for all values of money growth (left) …

Therefore, obvious question arises: Is Laffer curve for seignorage for real, or is it just figment of literature’s exclusive focus on Cagan’s ‘semi-log’?
This paper

I reconsider monetary dynamics of hyperinflations based on data from 20 episodes, from French Revolution to Venezuela under Nicolas Maduro …

I find no evidence of Laffer curve for seignorage: relationship between money growth and seignorage has been positive at all levels of money growth …

On the right, evidence for Hungary: as I will show, evidence for other countries is qualitatively the same …

There is no evidence that, beyond a threshold, increases in money growth cause decreases in seignorage …

Recall: post-WWII Hungary is highest hyperinflation ever recorded …
Natural explanation: hyperinflation data show clear preference for ‘log-log’ specification (or functional form close to it, such as Benati et al.’s, *JME* 2021) …

I show this has **material implications** for

1. **Theoretical analyses** of hyperinflations: e.g., compared to semi-log, with log-log steady-states’ **stability properties** are **reversed** …

2. Correctly characterizing **time-series properties** of hyperinflations: semi-log suggests largest root in the system is around 1.7, log-log that it is 1 …

   Hyperinflations have been **unit root** processes, not wildly explosive ones …

3. Interpretation of **specific episodes**: as corollary of (1), within context of Weimar Republic’s episode I provide interpretation of impact of invasion of Ruhr …
Implications

My evidence is fully compatible with standard narrative accounts of hyperinflations, from Bresciani-Turroni (1937) to Sargent (1982) …

However, model-based analyses—both theoretical and empirical—should be revised, as they are both based on empirically implausible money demand specification, and therefore present incorrect view of the world …
The dataset

20 episodes, from French Revolution to Venezuela under Nicolas Maduro …

Beyond standard datasets—e.g. Cagan’s, and Barro’s (JPE, 1970)—I consider several additional episodes, for which I obtained data from primary sources …

This is the case, e.g., for

- French Revolution: data are from books published in early XIX century …
- Chile, Argentina, Bolivia, Brazil, etc.: data are from central banks and national statistical agencies …

Table in next slide reports key features of dataset …

Following convention in literature, inflation is measured as monthly log-difference of price level …
Range of variation in inflation is extraordinary, from post-WWII Hungary’s peak of 33.67 … … to second and third most extreme episodes, Greece and Yugoslavia, with peaks of 13.66 and 11.29 … … down to the mildest, Chile, with peak of 0.58 … Such wide range of variation allows for strong identification …
Empirical relationship between money growth and seignorage

Seignorage estimates for Hungary I showed before are from Sargent and Wallace (IER, 1973) …
Sargent and Wallace computed estimates, but did not plot them together with money growth …
If they had done it, they would have seen Laffer curve they study based on semi-log is not in the data …
My findings have been hiding in plain sight since 1973 …
Next two slides show
• all of Sargent and Wallace’s estimates for Cagan’s dataset, and
• joint evidence for all episodes in my dataset, controlling for country-specific fixed effects …
No evidence of Laffer curve, i.e. that beyond a threshold, increases in money growth cause decreases in seignorage …
The logarithm of Sargent and Wallace’s (1973) measure of seignorage plotted against the logarithm of money growth from Cagan (1956)
Evidence from regressing log seignorage on log money growth: logarithm of seignorage minus estimated country-specific fixed effects
What is most plausible money demand specification?

Semi-log implies Laffer curve, whereas log-log implies what you see in the data …

Therefore, alternative way of addressing this issue is exploring which specification is more empirically plausible …

Benati, Lucas, Nicolini, and Weber (JME, 2021): in dataset of 44 countries since WWI data clearly prefer log-log …

We have lots of statistical evidence, but next slide shows simple visual evidence for selected countries, plotting minus log money balances over nominal GDP together with

- **top row**: level of nominal interest rate
- **bottom row**: logarithm of nominal interest rate

Top row corresponds to semi-log, bottom row to log-log …

Evidence is very clear: log-log is significantly more plausible than semi-log …
We did not specifically analyze hyperinflations, which typically last at most 2 years: What about them? Table in next slide shows results from model comparison exercise based on panel VARs with country-specific fixed-effects: semi-log versus log-log ...

Evidence is overwhelming: minimum of distribution of log-likelihood based on log-log is uniformly greater than maximum of distribution based on semi-log ...
Clear evidence that empirically most plausible functional form for hyperinflations is log-log …

Right: log real money balances and minus either inflation (i.e., semi-log) or log inflation (i.e., log-log): again, for hyperinflations log-log is clearly more empirically plausible …

Evidence for Yugoslavia is especially stark …
Implications, I: Time-series properties of hyperinflations

Evidence from panel VARs for the logarithm of real money balances and either inflation or log inflation: point estimates for the four largest eigenvalues, and fractions of bootstrap replications for which the eigenvalues are greater than 1

<table>
<thead>
<tr>
<th></th>
<th>$\lambda_1$</th>
<th>$\lambda_2$</th>
<th>$\lambda_3$</th>
<th>$\lambda_4$</th>
<th>$\lambda_1$</th>
<th>$\lambda_2$</th>
<th>$\lambda_3$</th>
<th>$\lambda_4$</th>
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<tbody>
<tr>
<td>$p=2$</td>
<td>0.330</td>
<td>0.330</td>
<td>0.937</td>
<td>1.728</td>
<td>0.876</td>
<td>0.816</td>
<td>0.534</td>
<td>0.124</td>
</tr>
<tr>
<td>$p=4$</td>
<td>0.631</td>
<td>0.631</td>
<td>0.924</td>
<td>1.680</td>
<td>0.795</td>
<td>0.746</td>
<td>0.550</td>
<td>0.063</td>
</tr>
</tbody>
</table>

I: Based on Cagan’s (1956) semi-log

II: Based on Meltzer’s (1963) log-log

With semi-log largest eigenvalue is explosive, and very large, around 1.7 …

With log-log it is indistinguishable from exact unit root …

Alternative functional forms provide different characterization of time-series properties of hyperinflations …

Most plausible characterization: hyperinflations driven by random-walk process …

What was it? On this, more later …
Implications, II: Theoretical analyses of hyperinflations

First implication: as mentioned, semi-log implies Laffer curve for seignorage, whereas log-log implies positive relationship at all levels of money growth and inflation …

Second implication: equilibria stability properties get reversed, with high-inflation equilibrium becoming unstable …

Left: GG curve is government budget constraint …
Economy is always on GG curve, where government finances budget deficit by printing money …

Equilibrium is at intersection of GG curve and 45° line, where, up to constant, expected inflation is equal to money growth …
With semi-log, under rational expectations high-inflation steady-state is stable: Sargent and Wallace’s (IER, 1973) classic result …

However, with log-log high-inflation steady-state is unstable: beyond it lies region of ‘runaway inflation’ …

This provides simple explanation for empirical fact: in several (although not all) cases, inflation literally ‘takes off’ towards latest stages of hyperinflation (see left) …

Possible explanation: large shock causes economy to jump beyond high-inflation steady-state B, into region of ‘runaway inflation’ …
Evidence for Weimar Republic is compatible with this interpretation …

Until end of 1922, inflation had been high, but not explosive …

In January 1923, France occupied Ruhr: as pointed out by Bresciani-Turroni (1937), this ‘gave the coup de grâce to the national finances and the German mark. Because of it some important sources of income were lost to the State.’

Possible interpretation of occupation of Ruhr—and resulting explosion of budget deficit financed via seignorage—is as shock that pushed economy into region of ‘runaway inflation’ …
An estimated model of Weimar Republic’s hyperinflation

Left, key data: government budget deficit in Gold Marks (i.e., in real terms) and money balances (as fraction of income) from Bresciani-Turroni (1937); and inflation, seignorage, and exchange rate depreciation ...

In line with Bresciani-Turroni (1937) and Sargent (1982), I assume key driver of hyperinflation is evolution of budget deficit, which is financed by printing money ...
Logarithm of budget deficit, $d_t$, is sum of 2 orthogonal components, a random-walk with drift and a stationary AR(1):

$$d_t = d_t^P + d_t^T$$

$$d_t^P = \mu_d + d_{t-1}^P + \epsilon_t^P$$

$$d_t^T = \rho_T d_{t-1}^T + \epsilon_t^T$$

with $\epsilon_t^P$ and $\epsilon_t^T$ being white noise orthogonal shocks …

Seignorage is computed based on the geometric average

$$\xi_t \equiv \theta_t \left[ \left( \frac{M_{t-1}}{P_{t-1}} \right)^{\omega} \left( \frac{M_t}{P_t} \right)^{1-\omega} \right]$$

where $M_t$ and $P_t$ are the nominal money stock and the price level, $\theta_t$ is money growth, and $\omega = 0.5$ …

Bresciani-Turroni (1937) conjectured that since hyperinflations follow exponential dynamics, geometric averages are more appropriate …
I show mathematically that Bresciani-Turroni was right ... Based on previous figure showing raw data, I assume that government sets log seigniorage equal to permanent component of budget deficit, \( d_t^P \):

\[
\ln \xi_t = d_t^P
\]

The demand for real money balances as fraction of income takes Meltzer’s log-log form

\[
\ln \left( \frac{M_t}{P_t Y_t} \right) = A - B \ln \pi_{t+1|t} + u_t
\]

with velocity shock \( u_t \) following a stationary AR(1)

\[
u_t = \rho_u u_{t-1} + \nu_t.
\]

Finally, nominal exchange rate depreciation, \( \Delta e_t \), is equal to inflation, \( \pi_t \), plus a PPP white noise disturbance:

\[
\Delta e_t = \pi_t + \varepsilon_t.
\]
Everything is driven by random-walk in budget deficit, \(d_t^P\): all variables are therefore \textit{stationarized} by \(d_t^P\) …

Model is \textbf{highly non-linear}, so will have to be estimated via \textit{particle filter} …

I show \textbf{preliminary} results based on \textbf{MLE}, with likelihood computed via Harvey’s (1989) ‘generalized Kalman filter’, based on Taylor expansion of non-linear state-space form …

In estimation I impose \textbf{determinacy}: future extensions will allow for either (\(i\)) \textbf{indeterminacy}, or (\(ii\)) \textbf{temporarily explosive} paths as in Ascarì, Bonomolo, and Lopes (\textit{AER}, 2019) …

A main result pertains to estimated relationship between money growth and seignorage as fraction of GDP …
At peak of hyperinflation, inflation was equal to nearly 6 on log scale …
Estimated relationship (right) suggests that at peak government was collecting nearly 25% of output via seignorage …
To put this into perspective: based on Cagan’s semi-log, standard estimates of maximum amount of seignorage government can raise in steady-state are around 10% …

Alternative functional forms for money demand have material implications beyond presence/absence of Laffer curve for seignorage …
Summing up

Data for 20 hyperinflations provide no evidence of Laffer curve: historically, relationship between money growth and seignorage has been positive for all values of money growth …

Natural explanation: entire literature based on Cagan’s semi-log functional form, which imposes Laffer curve upon data …

However, data clearly prefer log-log, which implies positive relationship between money growth and seignorage for all values of money growth …

Obvious question: Would this hold even if inflation exploded to infinity? Obviously not: in that case agents would switch to barter, and seignorage would collapse to zero …

My point is rather that threshold beyond which agents stop using money and seignorage becomes zero has never been crossed …
Background slides
I: Additional results from Benati, Lucas, Nicolini, and Weber (JME, 2021)
Evidence from Wright’s (2000) cointegration tests

Table 2: Results from the Wright (2000) test: 90% coverage confidence intervals for the second element of the normalized cointegration vector.

<table>
<thead>
<tr>
<th>Country</th>
<th>Period</th>
<th>Søder-Latsø</th>
<th>Log-log</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>1922-2016</td>
<td>[-0.529; -0.417]</td>
<td>NCD</td>
</tr>
<tr>
<td>US - M1</td>
<td>1915-2017</td>
<td>[-0.613; -0.393]</td>
<td>NCD</td>
</tr>
<tr>
<td>US - M1,MMDAs</td>
<td>1915-2017</td>
<td>[-0.352; -0.108]</td>
<td>NCD</td>
</tr>
<tr>
<td>Argentina</td>
<td>1914-2009</td>
<td>[-0.107; -0.087]</td>
<td>NCD</td>
</tr>
<tr>
<td>Brazil</td>
<td>1934-2014</td>
<td>[-0.065; -0.009]</td>
<td>NCD</td>
</tr>
<tr>
<td>Canada</td>
<td>1926-2006</td>
<td>[-1.190; -1.053]</td>
<td>NCD</td>
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<tr>
<td>Colombia</td>
<td>1960-2017</td>
<td>[-0.578; -0.494]</td>
<td>NCD</td>
</tr>
<tr>
<td>Colombia</td>
<td>1980-2017</td>
<td>[-0.752; -0.448]</td>
<td>NCD</td>
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<tr>
<td>Guatemala</td>
<td>1980-2017</td>
<td>[-0.678; -0.414]</td>
<td>NCD</td>
</tr>
<tr>
<td>New Zealand</td>
<td>1934-2017</td>
<td>[-0.589; -0.312]</td>
<td>NCD</td>
</tr>
<tr>
<td>Switzerland</td>
<td>1948-2005</td>
<td>[-0.369; -0.193]</td>
<td>NCD</td>
</tr>
<tr>
<td>Bolivia</td>
<td>1980-2017</td>
<td>[-0.520; -0.388]</td>
<td>NCD</td>
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<tr>
<td>Israel</td>
<td>1983-2016</td>
<td>[-0.386; -0.320]</td>
<td>NCD</td>
</tr>
<tr>
<td>Mexico</td>
<td>1985-2014</td>
<td>[-0.260; -0.184]</td>
<td>NCD</td>
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<td>Belgium</td>
<td>1946-1990</td>
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<td>Belize</td>
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<td>Austria</td>
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<td>Bahrain</td>
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<td>Barbados</td>
<td>1975-2016</td>
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<td>Ecuador</td>
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<td>Netherlands</td>
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<td>South Korea</td>
<td>1970-2017</td>
<td>[-0.639; -0.386]</td>
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<td>Thailand</td>
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<td>Australia</td>
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<td>Chile</td>
<td>1969-2017</td>
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<td>China</td>
<td>1940-1995</td>
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<td>Finland</td>
<td>1946-1985</td>
<td>[-0.530; -0.414]</td>
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<tr>
<td>Japan</td>
<td>1955-2017</td>
<td>[-0.513; -0.125]</td>
<td>NCD</td>
</tr>
<tr>
<td>Spain</td>
<td>1941-1989</td>
<td>[-0.163; -0.159]</td>
<td>NCD</td>
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<tr>
<td>Taiwan</td>
<td>1962-2017</td>
<td>[-0.453; -0.253]</td>
<td>NCD</td>
</tr>
<tr>
<td>Turkey</td>
<td>1968-2017</td>
<td>[-0.963; 0.931]</td>
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<td>West Germany</td>
<td>1960-1989</td>
<td>[-0.489; 0.692]</td>
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<td>Italy</td>
<td>1949-1996</td>
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<td>Norway</td>
<td>1946-2014</td>
<td>[-0.961; 0.985]</td>
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<td>Paraguay</td>
<td>1962-2015</td>
<td>[0.328; 0.125]</td>
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<td>Peru</td>
<td>1959-2017</td>
<td>[-0.402; 0.026]</td>
<td>NCD</td>
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<td>Portugal</td>
<td>1914-1998</td>
<td>[-0.018; 0.210]</td>
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<tr>
<td>South Africa</td>
<td>1965-2015</td>
<td>[-0.170; 0.427]</td>
<td>NCD</td>
</tr>
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</table>

NCD = No cointegration detected.
Estimated elasticity of money demand based on Meltzer’s (1963) ‘log-log’ functional form
II: Additional evidence from the present work
The logarithms of money growth and seignorage for all 20 hyperinflations

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Based on Cagan's data; Based on Barro's data; Based on Graham's data;
Evidence from an estimated DSGE model for the Weimar Republic: the demand for real money balances and the relationship between money growth and seignorage (median, and 16-84 and 5-95 credible sets)
Money growth and seignorage in the Confederacy during the U.S. Civil War
Germany, June 1921-November 1923 (based on weekly data)
Definition of seignorage

By defining the money stock, real GDP, and the price level as $M_t$, $Y_t$, and $P_t$, the instantaneous revenue from money creation—i.e. seignorage—expressed as a fraction of GDP is defined as

$$\xi_t \equiv \frac{dM_t}{dt} \frac{1}{P_t Y_t} = \left(\frac{dM_t}{dt} \frac{1}{M_t}\right) \frac{M_t}{P_t Y_t} = \theta_t \frac{M_t}{P_t Y_t}$$

(1)

where $\theta_t$ is instantaneous money growth, and $M_t/(P_t Y_t)$ is the demand for real money balances expressed as a fraction of GDP.
Benati, Lucas, Nicolini and Weber’s (JME, 2021) money demand

Appendix A describes in detail the model of the transaction demand for money proposed by Benati et al. (2021). The model generalizes the framework proposed by Baumol (1952) and Tobin (1956) by allowing for several alternative functional forms for the cost of making transactions as a function of the number of ‘trips to the bank’, $n_t$. Notice that within this framework $n_t$ is the velocity of money, i.e. the ratio between nominal GDP and nominal money balances, and its inverse is therefore the demand for money balances as a fraction of GDP:

$$\frac{1}{n_t} = \frac{M_t}{P_t Y_t}.$$ \hspace{1cm} (8)

Whereas Baumol and Tobin assumed that the cost of making transactions increases linearly with $n_t$, Benati et al.’s (2021) benchmark functional form is given by

$$\theta(n_t) = \psi n_t^\sigma$$ \hspace{1cm} (9)

where $\psi$ and $\sigma$ are positive constants (with $\sigma = 1$ we obtain the Baumol-Tobin case). Notice that $\psi n_t^\sigma$ is the welfare cost of inflation expressed as a fraction of maximum potential output.

When the cost of making transactions is described by (9), the solution for $n_t$ is

$$\sigma \psi \frac{n_t^{\sigma+1}}{1 - \psi n_t^\sigma} = R_t = \pi_t^e$$ \hspace{1cm} (10)
Evidence on the similarity between Meltzer’s (1963) log-log and Benati, Lucas, Nicolini and Weber’s (2021) money demand
In order to replicate the fall in real money balances associated with increases in the inflation rate, and therefore in expected inflation, in expression (10) it ought to be the case that $1 - \psi n_t^\sigma > 0$, which implies that the welfare cost of inflation expressed as a fraction of maximum potential output ought to be smaller than one. Since all of the 20 hyperinflations analyzed herein have been characterized by dramatic collapses in real money balances, in what follows I assume that this condition is satisfied.

By combining expressions (1) and (8), log seignorage is given by

$$\ln \xi_t = \ln \theta_t - \ln n_t$$

Taking logarithms of (10), and then taking derivatives with respect to time, we obtain

$$\frac{d \ln \pi_t^\varepsilon}{dt} = \frac{(1 + \sigma) - \psi n_t^\sigma}{1 - \psi n_t^\sigma} \left[ \frac{d \ln n_t}{dt} \right]$$

By the same token, taking logarithms of (8), and then taking derivatives with respect to time, we obtain

$$\frac{d \ln n_t}{dt} = \pi_t - \theta_t$$

Combining (13) and (14) we obtain

$$\frac{d \ln \pi_t^\varepsilon}{dt} = \frac{(1 + \sigma) - \psi n_t^\sigma}{1 - \psi n_t^\sigma} \left[ \pi_t - \theta_t \right] = \Psi(n_t) \left[ \pi_t - \theta_t \right]$$
As previously discussed, the empirically relevant case is $1 - \psi n_t^e = \Psi(n_t) > 0$. The solution for money growth, money velocity (and therefore its inverse, the demand for real money balances as a fraction of GDP), inflation, and seignorage is fully characterized by equations (10), (12), and (15).

### 2.2.1 Steady-state and dynamics

In the steady-state $d\ln \pi_t^e/dt = 0$ and $\pi_t = \pi_t^e$, so that once again expression (7), $\pi_t = \pi_t^e = \theta_t$. holds. Within the present context the GG curve becomes

$$
\pi_t^e = \sigma \psi \frac{\theta_t^{\sigma + 1} \xi^{-(\sigma + 1)}}{1 - \psi \theta_t^{\sigma} \xi^{-\sigma}}
$$

(16)

where once again $\xi$, which is assumed to be exogenously given, acts as a shifter for the GG curve. The steady-state equilibrium lies at the intersection between this curve and the 45 degree line (7).
It can be trivially shown that, from a qualitative point of view, both the shape of the GG curve, and the dynamical properties of the system, are exactly the same as those for the log-log that are shown in the right hand-side panel of Figure 1. In particular, since in equation (15) $\Psi(n_t) > 0$, this expression implies once again that when the economy’s position on the GG curve is below (above) the 45 degrees line, so that $\pi_t - \theta_t < 0 \,(> 0)$, $d \ln \pi_t^e/dt < 0 \,(> 0)$. Once again the implication is that the steady-state A is stable, whereas the steady-state B is unstable, and beyond it lies a region of explosive inflation.

2.2.2 Money growth, velocity and seignorage in the steady-state

Based on the solution (10) and the fact that in the steady-state $n_t = n$ and $\pi_t^e = \theta$, by differentiating we obtain

$$
\frac{dn}{d\theta} = \left( (\sigma + 1)\sigma \psi n_t^\sigma + \left( \frac{\sigma \psi n_t^\sigma}{1 - \psi n_t^\sigma} \right)^2 \right)^{-1} > 0
$$

(17)

which implies that velocity is uniformly increasing in money growth. Finally, by the same token

$$
\frac{d\xi}{d\theta} = \frac{(\sigma + \xi)\psi^\frac{1}{\sigma} \left( 1 + \frac{\sigma}{\xi} \right)^{\frac{1}{\sigma}}}{1 + \sigma + \xi} > 0
$$

(18)

which implies that in the steady-state seignorage is also uniformly increasing in money growth. I now turn to a brief overview of the literature.
3.1 Cagan (1956) on the most appropriate functional form for the demand for real money balances

Cagan (1956) did not derive the semi-log specification (2) within a micro-founded framework, but rather simply postulated it.\(^4\) In reaction to the empirical shortcomings of the postulated specification for the latest stages of hyperinflations, for which the models’ fit had typically been worse than for the initial stages,\(^5\) he speculated that an alternative functional form may be needed in order to provide a better characterization of the data. In particular, he conjectured\(^6\)

’[...] that the function that determines the demand for real cash balances does not conform to [the semi-log functional form]. To be consistent with the data, this hypothesis requires that all observations that lie to the right of the linear regression shall fall in order along some curved regression function [...]’

In practice, this means that the alternative specification he was speculating about should have been either a log-log, or a functional form close to it. In the end, however, Cagan’s solution\(^7\) was neither to use a log-log, nor a specification close to it, but rather to simply exclude, in some cases, the latest observations from the empirical analysis:
‘The periods covered by the statistical analysis exclude some of the observations near the end of the hyperinflations. The excluded observations are from the German, Greek, and second Hungarian hyperinflations [...] . All the excluded observations lie considerably to the right of the regression lines, and their inclusion in the statistical analysis would improperly alter the estimates of $\alpha$ and $\beta$ derived from the earlier observations of the hyperinflation.’

It is to be noticed that the three episodes whose latest observations Cagan excluded from the analysis are the most extreme in his dataset, i.e. those which, for the purpose of discriminating between the semi-log and the log-log, are the most informative.

### 6.3 Evidence from a VAR-based model comparison exercise

The evidence in the previous two sub-sections is especially persuasive because it is based on the raw data. In this section I complement it with the following model comparison exercise. Based on both all of the 20 episodes considered jointly, and the 10 episodes with either the highest or the lowest median inflation rates, I estimate via maximum likelihood the following two specifications for the joint dynamics of the logarithm of real money balances and inflation:
\[
\begin{bmatrix}
\hat{m}_{i,t} \\
\pi_{i,t}
\end{bmatrix}
= \begin{bmatrix}
c_i^m + A(L)\hat{m}_{i,t-1} + B(L)\pi_{i,t-1} + \epsilon_i^{m} \\
c_i^{\pi} + C(L)\hat{m}_{i,t-1} + D(L)\pi_{i,t-1} + \epsilon_i^{\pi}
\end{bmatrix}
\] (22)

and

\[
\begin{bmatrix}
\hat{m}_{i,t} \\
\pi_{i,t}
\end{bmatrix}
= \begin{bmatrix}
c_i^m + A(L)\hat{m}_{i,t-1} + B(L)\pi_{i,t-1} + \epsilon_i^{m} \\
c_i^{\pi} + \exp\left\{C(L)\hat{m}_{i,t-1} + D(L)\pi_{i,t-1}\right\} + \epsilon_i^{\pi}
\end{bmatrix}
\] (23)

where \(i\) indexes the country; \(t\) indexes the month; \(\hat{m}_{i,t} \equiv \ln(M_{i,t}/P_{i,t})\); \(\hat{\pi}_{i,t} \equiv \ln(\pi_{i,t})\); \(A(L), B(L), C(L),\) and \(D(L)\) are polynomials in the lag operator, \(L\); \(c_i^m\) and \(c_i^{\pi}\) are country-specific intercepts; and \(\epsilon_i^{m}\) and \(\epsilon_i^{\pi}\) are country-specific residuals, which I postulate to follow a bivariate normal distribution with a non-diagonal covariance matrix. Equation (22) describes a panel VAR model with country-specific fixed-effects for log real money balances and inflation, and it therefore corresponds to the semi-log specification. Expression (23), on the other hand, postulates that, up to country-specific dummies and random disturbances, the joint dynamics of real money balances and inflation is described by

\[
\begin{bmatrix}
\hat{m}_{i,t} \\
\pi_{i,t}
\end{bmatrix}
= \begin{bmatrix}
A(L) & B(L) \\
C(L) & D(L)
\end{bmatrix}
\begin{bmatrix}
\hat{m}_{i,t-1} \\
\pi_{i,t-1}
\end{bmatrix}
\] (24)

corresponding to the log-log specification. By casting (24) into the form (23)—i.e., taking as the dependent variable, in the second equation, the \textit{level} of inflation, rather than its logarithm—it is possible to meaningfully compare, in terms of log-likelihood, which of the two functional forms provides the most plausible description of the data. As we will see, evidence overwhelmingly favors the log-log.\textsuperscript{24}
Estimating the elasticity of money demand based on the ‘log-log’

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Evidence from panel cointegrated VARs for the logarithms of real money balances and inflation: point estimates of the elasticity, 90% bootstrapped confidence interval, and fractions of bootstrap replications for which the elasticity is smaller than -1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Point estimates, and 90% confidence interval</td>
</tr>
<tr>
<td></td>
<td>Based on all 20 episodes</td>
</tr>
<tr>
<td>$k=1$</td>
<td>-0.502 [-0.593; -0.412]</td>
</tr>
<tr>
<td>$k=2$</td>
<td>-0.554 [-0.656; -0.454]</td>
</tr>
<tr>
<td></td>
<td>Based on 10 episodes with highest median inflation</td>
</tr>
<tr>
<td>$k=1$</td>
<td>-0.792 [-0.896; -0.681]</td>
</tr>
<tr>
<td>$k=2$</td>
<td>-0.926 [-1.041; -0.796]</td>
</tr>
<tr>
<td></td>
<td>Based on 10 episodes with lowest median inflation</td>
</tr>
<tr>
<td>$k=1$</td>
<td>-0.295 [-0.392; -0.191]</td>
</tr>
<tr>
<td>$k=2$</td>
<td>-0.312 [-0.412; -0.202]</td>
</tr>
</tbody>
</table>