Expected Survival Time of an Exchange Rate Band with Intra-marginal Interventions

by

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Abstract

The size of a speculative attack is calculated for an exchange rate target zone with intra-marginal interventions. Using these values, we calculate the expected survival time of a target zone. We see that this yields more reasonable values for a unilateral target zone compared to a target zone model with marginal interventions. The expected survival time does not depend on the bandwidth and the speculative attacks can happen at any point inside the band with almost equal probability. We also complete some sensitivity analysis and apply our method to obtain the survival time of the "Swedish" target zone.

JEL: E52, F31, F33

Key words: Target zone, intra-marginal interventions, mean reversion, speculative attacks, regime switching

1 Introduction

We calculate the expected survival time of a target zone when the interventions of the central bank are intra-marginal. The first structural modeling of the exchange rate dynamics in a target zone by Krugman [14] assumed that the central bank intervenes the exchange rate only at the boundaries. However, subsequent tests of this model rejected its implications (e.g. Flood, Rose and Mathieson [8] and Lindberg and Soderlind [17]). It has been observed that the intra-marginal interventions model discussed by Delgado and Dumas [4] and Froot and Obstfeld [11] fits exchange rates dynamics in a target zone better. Also the data released by the central banks (see, for example, Giavazzi and Giovannini [12] and Lindberg and Soderlind [16]) indicate that the interventions are intra-marginal.

A central bank can defend a target zone indefinitely, for example, by increasing the interest rate to sufficiently high values. However, typically a target zone is used to create a stable exchange rate which, in turn, contributes to the stability of internal macro variables. But a very high interest rate to defend the band contradicts the original purpose of implementing a target zone since it may induce instability in the economy. So we expect that the central bank set aside a fixed amount of reserves to defend the band. As discussed by Krugman and Rotemberg [15] even when the amount of reserves are known by the market, as long as this does not affect the dynamics of the exchange rate inside the band, we still expect a credible target zone if the reserves are sufficiently high. However after some time the reserves will deplete and there will be a speculative attack on the exchange rate. The target zone will either be realigned or collapse to a free floating regime. In this paper, we assume the latter.

Previously Flood and Garber [9] Buiter [3] among others, calculated the expected survival time of a fixed exchange rate regime, which can be regarded as a narrow exchange rate band. Dumas and Svensson [7] did similar calculations for a target zone with marginal interventions. They indicated that their calibrated calculations do not seem to fit the real life experience. The survival time in some cases for a reasonable amount of reserves is in order of centuries. In this paper we attempt to see if the survival time is more feasible if we use the intra-marginal interventions model which fits the real life target zone experience better. We observe that there is a substantial improvement in the expected survival time. We also observe that the survival time does not change substantially with the size of the band. The collapse can happen at any exchange rate away from the center of the band with almost equal chance. Hence a speculative attack can happen almost anywhere in the band with equal probability except at the boundaries where there is a higher chance of attack. This is of course contradictory to Krugman's model where the collapse can only happen at the boundaries but it is in accordance with the previous target zone experiences.

In the next section we discuss target zone models. In Section 3 we show how to calculate the expected survival time of a target zone with intra-marginal interventions. We calibrate our approach to the parameters of the Swedish target zone experience in Section 4. We discuss possible extensions in the last section.

2 Target Zone Models

2.1 Marginal Interventions

In a target zone, the exchange rate of a country is restricted between two values, $\underline{x}$ and $\bar{x}$, by the central bank of the country. The research on various aspects of a target zone took off after Krugman [14] modeled the exchange rate dynamics in a target zone. In his model, the logarithm of the exchange rate of home country x, the value of foreign money in terms of domestic money, is a function of its fundamental f and the expected rate of change in the exchange rate:

$$x_t = f_t + \alpha E[dx_t]/dt \tag{1}$$

where α is the semi-elasticity of the exchange rate with respect to the expected exchange rate depreciation. The fundamental is defined as

$$f_t = m_t + v_t. \tag{2}$$

Here $m_t = \ln(R_t + D_t)$ is the logarithm of the money stock, where R_t and D_t are the foreign reserves and the domestic credit, and the velocity v_t is an exogenous monetary shock. The money stock changes only at the boundary of the target zone.

$$dm_t = dL_t - dU_t, \tag{3}$$

where dL_t and dU_t are positive only when $x = \underline{x}$ and $x = \bar{x}$ respectively[1]. We will assume that commodity prices are flexible, purchasing power parity and uncovered interest rate parity hold, and there is full capital mobility.

Originally, Krugman assumed that the interventions are made at the boundaries of the target zone (marginal interventions) and they are infinitesimal. In this case we assume that v_t is a Brownian motion with a non-zero constant drift;

$$dv_t = \mu dt + \sigma dB_t, \tag{4}$$

where B_t is the standard Brownian motion. The solution to this system is calculated by, among others, Krugman [14] for $\mu = 0$ and by Delgado and Dumas [4] for the general case. The log of the exchange rate is given as a function of the fundamental;

$$x_t = f_t + \alpha\mu + Ae^{\lambda_1 f_t} + Be^{\lambda_2 f_t} \tag{5}$$

where

$$\lambda_{1,2} = \frac{-\mu\alpha \mp \sqrt{\mu^2\alpha^2 + \sigma^2}}{\sigma^2\alpha}.$$

[1] Svensson [20] has a complete nontechnical treatise of target zone models.

The constants A and B; and the bounds on the fundamentals[2] can be obtained by using the boundary conditions

$$x(\bar{f}) = \bar{x}; \qquad x(\underline{f}) = \underline{x}; \qquad \frac{dx}{df}(\bar{f}) = \frac{dx}{df}(\underline{f}) = 0: \tag{6}$$

The last two equalities follow from the 'smooth pasting' conditions. The explicit expressions for $\bar{f}$ and $\underline{f}$ can be found in Delgado and Dumas [4]. The constants A and B are given in Froot and Obstfeld [11] or in Krugman and Rotemberg [15]. The free float solution to this system corresponds to "no bubble" case, i.e., $A = B = 0$, and $x_t = f_t + \alpha\mu$:

2.2 Intra-marginal Interventions

Using the data from EMS and the Nordic countries, Krugman's original target zone model has been tested. The model above implies that the distribution of the exchange rate within the band must be U-shaped. But the data shows that the distribution is hump-shaped. Also the nonlinear relation between the exchange rate and the fundamental cannot be shown to exist. It is also known that interventions made by the central banks are not only at the boundaries but also inside the target zone. For example, Lindberg and Soderlind [16] discuss the interventions made by the Riksbank and indicate that intra-marginal intervention is a rule rather than an exception. Hence extensions to the original model seem necessary.

A mean reverting stochastic process for the fundamental would generate a hump-shaped exchange rate distribution. Also, the exchange rate function will be almost linear in fundamentals. Lindberg and Soderlind [16] considering an intra-marginal intervention policy, managed to obtain a hump-shaped distribution with some mass at the edges of the band. The overall fit of their model to the data was quite good compared to the marginal interventions model.

Here, we will use an AR(1) process to model the exchange rate dynamics in the band. Equation (1) still defines the relation between the exchange rate and the fundamental. The fundamental is given by (2). The drift of the velocity is now zero, $dv_t = \sigma dB_t$: Since the intervention policy is changed, the equation (3) will be different. We assume that the monetary authority will intervene continuously with increasing size as the exchange rate moves away from some preferred level x_c[3].

$$dm_t = -\rho[f_t - f_c]dt + dL_t - dU_t \tag{7}$$

ρ is a policy parameter. dL_t and dU_t are same as in (3) and f_c corresponds to the preferred exchange rate level, $x_c = x_t(f_c)$.

[2] Delgado and Dumas [4] shows that there is a monotonic relation between the band on the fundamentals and the band on the exchange rate.

[3] This corresponds to supply shock interpretation of the mean reverting process as discussed by Delgado and Dumas [4]

Delgado and Dumas [4] and Froot and Obstfeld [10] found the solution to this system as

$$x_t = \frac{f_t + \alpha\rho f_c}{1+\alpha\rho} + A M\left(\frac{1}{2\alpha\rho}, \frac{1}{2}, \eta_t^2\right) + B M\left(\frac{1+\alpha\rho}{2\alpha\rho}, \frac{3}{2}, \eta_t^2\right)\eta_t, \tag{8}$$

where $\eta_t = \sqrt{\rho}(f_c - f_t)/\sigma$ and $M(\cdot,\cdot,\cdot)$ is Krummer's function.

$$M(a;b;x) = \frac{\Gamma(b)}{\Gamma(a)} \sum_{n=0}^{\infty} \frac{\Gamma(a+n)}{\Gamma(b+n)} \frac{x^n}{n!}$$

Γ is the gamma function, $\Gamma(z) = \int_0^\infty x^{z-1} e^{-x} dx;\ z > 0$. A and B are the constants of integration to be determined by the boundary conditions (6) and the condition $x_c = x_t(f_c)$. The free-float solution in this case is $x_t = f_t$.

3 Speculative Attacks and the Collapse of a Target Zone

In this paper, we will consider the collapse of a target zone into a free float regime. It will be assumed that the reserves of the central bank are limited but still enough to support a credible target zone[4]. Since the central bank has to intervene the exchange rate with limited reserves, after a while the reserves will deplete and the target zone will lose its credibility. This, in turn, will cause a speculative attack. It is possible to calculate the minimum amount of reserves, which is equal to the amount of the speculative attack at the moment of collapse, necessary to defend the target zone. While Krugman [13] and Flood and Garber [9] did this for fixed regimes, Krugman and Rotemberg [15] looked at the one-sided target zones[5]. Finally, Delgado and Dumas [5] obtained the level of reserves that triggers the speculative attack for the two-sided target zone for the marginal interventions model. In this section, after we show the minimum reserves for the marginal intervention model, we will obtain the same for the model with intra-marginal intervention.

The expectation of the foreign reserves falling to zero or to some unacceptable high level μ may trigger a buying attack or a selling attack. Since the reserve level in the marginal intervention case changes only at the boundaries, the speculative attacks will occur at the boundaries[6]. Since it is possible to forecast the attack by observing the reserve level, at the time of the collapse there will not be any change in the exchange rate level otherwise there would be an arbitrage opportunity. Hence only the fundamental will change at the collapse. Just before the collapse, the free float exchange rate corresponding to the fundamental $\bar{f}$ is $\bar{f} + \alpha\mu$, right after the collapse the exchange rate will stay $\bar{x}$. Hence the change in the fundamental should be $\bar{f} + \alpha\mu - \bar{x}$. If we assume the collapse is instantaneous the only change in the fundamental is the change

[4] Krugman and Rotemberg [15] discusses the necessary amount of reserves to sustain a credible target zone and how that is related to 'smooth pasting' condition.

[5] One-sided zone has only upper or lower bound and the central bank, in the case of marginal interventions, intervenes only at one end.

[6] Otherwise, it would not make sense to use a credible target zone model.

in the reserves. Therefore the size of the speculative attack is

$$\bar{a} = \bar{f} + \alpha\mu - \bar{x}. \tag{9}$$

We can also calculate the size of the selling attack at the lower boundary as

$$\underline{a} = \underline{x} - \alpha\mu - \underline{f}. \tag{10}$$

Therefore whenever the reserves fall below $\bar{a}$ and $x = \bar{x}$, there will be a buying attack and the target zone will collapse. Similarly, if the reserves are more than $\bar{r} - \underline{a}$ and $x = \underline{x}$, there will be a selling attack and the target zone will collapse.

In the case of intra-marginal interventions, the reserves change at any point inside the band. Therefore, the reserves can fall below (or raise above) a critical value at any exchange rate. If, at time t, the fundamental is f_t and the exchange rate is x_t, then the free float fundamental is x_t. Since after the collapse there is no expected change in the exchange rate, the change in the fundamental will be $f_t - x_t$, which is the critical value to trigger a speculative attack at that exchange rate. Hence the reserves at the time of an attack are given by

$$w_t(f) = \frac{\alpha\rho f_t - \alpha\rho f_c}{1+\alpha\rho} - AM\left(\frac{1}{2\alpha\rho}; \frac{1}{2}; \eta_t^2\right) - BM\left(\frac{1+\alpha\rho}{2\alpha\rho}; \frac{3}{2}; \eta_t^2\right)\eta_t. \tag{11}$$

If $m < 0$, there is a selling attack.

The collapse time of a target zone with the marginal interventions is obtained by Dumas and Svensson [7]. During the operation of a target zone it must be true that

$$\underline{a} \le m_t \le \bar{r} - \bar{a} \qquad \text{and} \qquad \underline{f} \le f_t \le \bar{f}.$$

This implies that the velocity $v_t = f_t - m_t$ must satisfy

$$\underline{f} - (\bar{r} - \bar{a}) \le v_t \le \bar{f} - \underline{a}.$$

The collapse will occur when v_t hits one of these bounds. Hence, Delgado and Svensson [7] indicated, the collapse time is equivalent to the first passage time of a Brownian motion. The survival expected time T, conditional upon initial levels r_0 and f_0, is given by

$$E[T|f_0; r_0] = (v_0 - (\underline{f} - (\bar{r} - \bar{a})))\cdot(\bar{f} - \underline{a} - v_0)/\sigma^2; \quad \text{for } \mu = 0; \tag{12}$$

$$E[T|f_0; r_0] = \frac{-v_0 + (\bar{r} - \bar{a})}{\mu} + \frac{(\bar{f} - \underline{a} - v_0)}{\mu} \times \frac{1 - e^{-\theta(v_0 - (\underline{f} - (\bar{r} - \bar{a})))}}{\mu(1 - e^{-\theta(\bar{f} - \underline{a} - v_0)})} \quad \text{for } \mu \ne 0; \tag{13}$$

where $v_0 = f_0 - r_0$ and $\theta = 2\mu/\sigma^2$.

Dumas and Svensson [7] applied this formula to calculate the expected survival time in the Swedish case, where the exchange rate band is ± 1.5 percent. They assumed that the standard deviation σ^2 and the drift are both 10 percent per year, which they admit to be quite large. They found out that a reserve level equal to 2.7 times the speculative attack size ($r - \underline{a} = 100$ log percent) brings about an expected survival time of 10-20 years. When they change μ to zero they obtained 120 years. As they pointed out, the recent Finnish and Swedish experience contrasted to these results.

In the intra-marginal interventions model, while the fundamental still is bounded by $\underline{f}$ and $\bar{f}$, the bound on reserves depends on the fundamental

$$f_t - x(f_t) = w(f_t) \leq m_t \leq f^1 - w(f_t) = f^1 - (f_t - x(f_t)). \tag{14}$$

This gives us a very complicated first time passage problem for a stochastic process, one in which the barriers depend on the process itself.

4 Computational Results and Discussions

Obtaining an explicit solution to this problem proved to be, if not impossible, very difficult. To obtain the results, we use Monte Carlo simulation of 15000 observations. The time increment in the discretization of the model is set to 300 periods per year[7].

First, we look at the 'Swedish' exchange rate band of ± 1.5 percent. The parameters are given by Lindberg and Soderlind [16] as $\alpha = 0.353571$, $\sigma = 0.0312163$, $\rho = 3.684211$, $x_c = -0.63\%$, $f^1 = 0.045445$, $\underline{f} = -0.031636$ and $f_c = -0.006530$. We choose r, the maximum size of reserves to trigger a collapse, as 2.5 times the initial reserves. The maximum size of the speculative attack is $f^1 - \bar{x}$. Figure 1 shows the expected survival time versus the reserves whose unit is the maximum size of the speculative attack. 2.7 times the speculative attack in the marginal attack case corresponds to 4.5 in the graph. For that we obtain 30 years of survival time. If the reserves are no more than 3 times the maximum size of a speculative attack, the survival time is about 15 years. Considering the fact that the Swedish target zone lasted about 10 years (from October 1982 to Fall 1992) in the longest case these values are comparable.

In the next step, we look at the effect of the bandwidth. We plot a symmetric target zone, ($\bar{x} - x_c = x_c - \underline{x}$), for different values of bandwidth $2\bar{x}$. We assumed that $x_c = 0$, $\alpha = 0.35$, $\rho = 3.68$, $\sigma = 0.03$ and $f_c = 0$. First, using (8) we solve for f^1 numerically for each $\bar{x}$. Then we set the reserve m_0 to be the largest value of the difference $f^1 - \bar{x}$ which corresponds to the largest value of $\bar{x}$ since $f^1 - \bar{x}$ is monotone in $\bar{x}$. We noticed that while the bandwidth changes between 0.02 to 0.14, the survival time stays around 3.5 years. When

[7] We experimented with changing the number of sample paths and discretization size for the first simulation below. Increasing both do not make a quantative difference in the result but it increases the simulation time substantially. The code is written in Gauss. We can supply it upon request.

Figure 1: Expected survival time of Swedish target zone as a function of reserves. Reserves are in units of minimum reserve amount to sustain a credible target zone.

$m_0 = 4.5(f^1 - 0.07)$ the survival time is fixed about 30 years. In the marginal intervention model, one can see from equations (12) and (13) that the expected survival time increases with f^1 or $\underline{f}$ which increases with $\bar{x}$ and $\underline{x}$ respectively. As Dumas and Svensson [7] observed, the bandwidth has a stronger effect on the survival time of a target zone with marginal interventions when the reserves are very low. In the intermarginal intervention model, the reserves are used inside the target zone to revert the direction of exchange rate and at the boundaries to keep the exchange rate inside the zone. As the bandwidth gets larger the probability that the exchange rate hits the boundary will decrease drastically and due to the mean reversion factor, the exchange rate will spend the majority of the time in the middle of the band. But the exchange rate will spent more time on one side of the band. Then the central bank will use more reserves to keep the exchange rate in the band and will not recover the reserves. Hence, the survival time is not a factor for the selection of the bandwidth[8].

We also look at the effect of the starting point of the exchange rate inside the target zone. Dumas and Svensson [7] found that for the marginal intervention target zone model, when the reserves have reached minimum, it would still take an expected time of 30 years for the target zone to collapse if the fundamental and the exchange rate start at the strong end of the band. Even with $\mu = 10\%$, it is about 10 years. Of course, this has implications for the realignments of the target zone since after a realignment, it will matter where to locate the exchange rate in the new zone because this will effect drastically the time of the next realignment.[9,10] When we run the Swedish target zone with $m_0 = 4(f^1 - \bar{x})$, we see that the survival time decreases monotonically from 27 years to 20 years as the initial value of the exchange rate in the band changes from the lower boundary to higher boundary. If we choose $m_0 = f^1 - \bar{x}$ then it changes from 3.5 years to 9 months. Hence the survival time is still sensitive to the initial location of the exchange rate in the band although the relation is weaker now since a substantial amount of reserves are used inside the band.

A consequence of intra-marginal intervention is the possibility of collapse of a target zone when the exchange rate is inside the band. This is of course more in accordance with the real life experience compared to the marginal intervention model, where a collapse can only occur at the boundaries. Next we look at

[8] The other factor for the size of the bandwidth is the monetary independence, see Svensson [20] for an excellent discussion, also Svensson [18] and Svensson [19] for the relation between the interest rate differentials and the bandwidth.

[9] Although we assumed that after the collapse, the exchange rate dynamics become free floating, if the realignments are decided endogenously (rather than given as exogenous shocks as in the realignment literature) the location of the exchange rate in the new band will be important for the timing of the next realignment.

[10] Bertola and Svensson [2] and Werner [21] assume that the exchange rate position within the band is unchanged. Dumas, Jennergen and Naslund [6] fixes the fundamental after the jump and calculates the new position of the exchange rate from the model. Ball and Roma [1] set the starting value as the mid-point of the new band. Bertola and Svensson [2] assumes that it starts from the strong end of the target zone. But, the realignment process in each of these papers is exogenous.

Figure 2: Probability of a collapse in a intra-marginal intervention target zone

the distribution of the location of a speculative attack and the collapse. We plot the density, calculated using a kernel smoothing method, for a symmetric target zone of $\mu = 1.5\%$, $\sigma = 0.031$, $\alpha = 0.035$, $x_c = 0$, $m_0 = 4(f^1 - \mu)$ and $r = 2.5 m_0$ in Figure 2. Besides some masses at the boundary of the band the density is concentrated in the middle between the center and the end points. Franc/DM target zone realigned in the middle of the upper part of the band 6 out of 7 realignments. The other experiences also show that the collapse is not necessarily at the boundary of the band. Our calculations indicate that the mass at the boundaries become negligible as the bandwidth gets larger.

We also did some sensitivity analysis. For a symmetric target zone of $\mu = 1.5\%$, $\sigma = 0.031$, $\alpha = 0.035$, $x_c = 0$ and $m_0 = 4.5(f^1 - \mu)$. As expected, the survival time decreases with ρ. But as ρ increases from 1 to 7, the survival time changes only 1.5 years. Also, Lindberg and Soderlind indicate that the loss function in the simulated moments estimator is flat in α direction. Hence we look at the sensitivity of survival time to α. For parameter values of $\mu = 1.5\%$, $\sigma = 0.031$, $\rho = 3.68$, $x_c = 0$ and $m_0 = 4.5(f^1 - \mu)$, when we change α from 0.1 to 0.5 the survival time stays between 12 to 13 years. Hence the results are not sensitive to α parameter.

Figure 3: Expected Survival time for different values of the drift of the velocity

5 Some Extensions

Although the model above seems to capture the collapse of a target zone more realistically, it still needs to be improved. One necessary improvement is the addition of a drift term to the velocity since in most cases the economic conditions in the domestic country is worsening over time. If we assume that the velocity of the fundamental is given as in (4) then we expect to have a shorter expected survival time since now the reserves are also spent to counter the effect of the positive drift of the fundamental. In this case, the solution to (1) is given by

$$x_t = \frac{f_t + \alpha\rho f_c + \alpha\mu}{1 + \alpha\rho} + A M\left(\frac{1}{2\alpha\rho}, \frac{1}{2}, \eta_t^2\right) + B M\left(\frac{1 + \alpha\rho}{2\alpha\rho}, \frac{3}{2}, \eta_t^2\right)\eta_t,$$

where $\eta_t = (\mu - \rho(f_c - f_t))/\sqrt{\rho}\sigma$. Since the free float solution is $x_t = f_t + \alpha\mu$, the reserves in the point of attack will be

$$w_t(f) = \frac{\alpha\rho(f_t + \alpha\mu - f_c)}{1 + \alpha\rho} - A M\left(\frac{1}{2\alpha\rho}, \frac{1}{2}, \eta_t^2\right) - B M\left(\frac{1 + \alpha\rho}{2\alpha\rho}, \frac{3}{2}, \eta_t^2\right)\eta_t.$$

We simulate the survival time for parameter values of $\chi = 1.5\%$, $\sigma = 0.031$, $\rho = 3.68$, $x_c = 0$; and $\mu = 0\%, 1\%$ and 3% in Figure 3. The drastic decrease in the survival time is clear in this case. The effect is stronger than the calculations given in Dumas and Svensson [7].

We can also use more general stochastic processes for the velocity and the fundamental since a more general process may improve the fit to the data. Let us assume that the velocity is an Itô process

$$dv = \mu(f_t)dt + \sigma(f_t)dB_t$$

and the interventions follow a more general mean reverting process $dm_t = -\rho(f_t)[f_t - f_c]dt + dL_t - dU_t$. If we assume that the exchange rate is twice differentiable function $x(f)$ of the fundamental, Itô's lemma will yield

$$E(dx)/dt = \mu(f)x'(f) + \frac{1}{2}\sigma^2(f)x''(f).$$

After we plug for $E(dx)/dt$ from (1) we obtain the second order differential equation

$$x(f) = f + \alpha(\mu(f) - \rho(f))x'(f) + \alpha\sigma^2(f)x''(f). \qquad (15)$$

Under certain smoothness assumptions on $\mu(f); \sigma^2(f)$ and $\rho(f)$, this equation has a unique solution $x(f)$. Then the bounds on reserves are given by (14) as $f_t - x(f_t) \leq m_t \leq \bar{r} - (f_t - x(f_t))$. Following the arguments of Section 3 we can find the bound on the reserves as

$$f_t - x(f_t) \leq m(f_t) \leq \bar{r} - (f_t - x(f_t)).$$

We can always solve approximately (15) with power series. Then numerical methods of the previous section enable us to calculate the survival time.

6 Conclusion

It was shown by Lindberg and Soderlind [16] and Ball and Roma [1] that the target zone models with intra-marginal interventions produce a better fit to the real life target zone experience. In this paper, we showed that it also yields a better result for the expected survival time than the target zone model with marginal interventions. In general, it is not possible to know the amount of reserves which a central bank is willing to spend to protect the zone. The amount of reserves can be thought as the commitment of the bank to the survival of the target zone. One important extension in this area would be to calculate the timing of a speculative attack to a realigning target zone, hence the calculation of the timing of realignment.

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