Wage Bargaining in an Optimal Control Framework: A Dynamic Version of the Right-to-Manage Model*

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Abstract

This paper aims at representing wage bargaining as an optimal control problem. Specifically, by assuming that employment follows a stock adjustment principle towards the maximising level of profits (labour demand), we build an intertemporal optimising model in which the real wage is continuously set by an infinitely-lived omniscient arbitrator that is called in to resolve the dispute between the workers and the employers. Our theoretical proposal allows to show that unions may speed up the adjustment to equilibrium and it suggests that standard (static) models may understate the distortions implied by wage bargaining.

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1 Introduction

There are two main approaches to modelling the bargaining behaviour as it was pioneered by Nash (1950, 1953): the *axiomatic* approach and the *game-theoretic* approach. The former aims at finding the weak set of axioms under which a unique outcome can be found[1]. The latter aims at building plausible non-cooperative games and determine - through their solution - the actual outcome of the bargaining process[2].

The negotiation between management and workers concerning wages is probably one of the most recurring application of the bargaining theory. In this field of theoretical labour economics, there are two competing framework to model wage bargaining, *i.e.*, the right-to-manage model and the efficient bargaining model. In the former, the union and the representative firm bargain over the wage while the employment is unilaterally chosen by the employer. In the latter, the union and the firm bargain simultaneously over the wage *and* employment. An excellent overview is given by Booth (1995).

Most of the models of collective bargaining are static in the sense that they do not explicitly consider the dynamic implication of negotiations on wages and employment. Of course, there are some good exceptions. Specifically, the seminal work by Booth and Schiantarelli (1987) provides a dynamic analysis of the monopoly union model developed with optimal control techniques aimed at assesing the employment effects of a reduction of the standard working week. Moreover, there is a paper by Kidd and Oswald (1987) that builds a dynamic model developed within an optimal control framework in which an utilitarian union pick a time path for employment (and, implicitly, the wage) by tacking into account its membership dynamics[3]. Finally, we find the work by Lockwood and Manning (1989) that derives a dynamic version of the right-to-manage and efficient bargaining model by exploiting dynamic programming techniques.

To our knowledge, the present contribution is the first attempt to explicitly model wage bargaining as a continuous process in an optimal control framework. For reasons of analytical tractability, this task is carried out in the context of the right-to-manage model. Specifically, we develop an intertemporal optimisation model developed in continuos time in which an infinitely-lived arbitrator is called to choose the real wage rate by tacking into account that employment adjusts towards the appropriate level that satisfies labour demand. This framework allows for a straightforward derivation of an explicit dynamic

[1] See, for example, Peters (1992).

[2] See, for example, Sutton (1986).

[3] Kidd and Oswald (1987) builds also a dynamic version of the efficient bargaining model in which wages result in being time-independent.

law for the real wage rate and a sharp analysis of the dynamic properties of an economy in which the employment path is affected by the time path of the wage and *vice versa*.

The remainder of the paper is arranged as follows. Section 2 presents the model, its local dynamics and some numerical examples. Section 3 concludes.

2 The Model

By following the principles of the optimal control theory, we develop an intertemporal optimisation model in which employment adjusts towards the level desired by employers, *i.e.*, towards labour demand. Therefore, by assuming perfect competition, employment dynamics derives from the standard profit-maximising behaviour assumption. In this sense, our model can be thought as a microfoundation of a supply-constrained equilibrium as it is described in the short-run dynamic model by Solow and Stiglitz (1968).

A distinctive feature of the present contribution is that the real wage is continuously set by an infinitely-lived omniscient arbitrator. Specifically, in each instant, our arbitrator is assumed to choose the real wage rate by weighting the objective functions of a group of identical (risk-averse) unionised workers and a representative firm. Our approach seems to provide a well-tested tool for describing the behaviour of a mediator whose job is precisely to settle a stream of bargaining conflicts. In other words, we view wage bargaining as a continuous process in which consecutive agreements take place while the parties' underlying opportunities constantly change. Thereafter, in contrast to the traditional approach, which assumes the presence of a single and constant set of payoff and predicts a single agreement, in our framework the parties's set of opportunities changes continuously over time and the solution specifies the whole path of agreements. Similar arguments may be found originally in Raiffa (1953) and, more recently, in Wiener and Winter (1998).

2.1 Employment Dynamics

In our framework, employment (L) adjusts towards the appropriate level desired by employers. In other words, as suggested by Booth and Schiantarelli (1987), we are making the *had hoc* assumption that employment follows a stock adjustment principle, whereby a fixed fraction of the gap between the equilibrium and the actual level of employment is closed at each point of time.

Suppose that the production function has a quadratic specification:

$$Y = \alpha_1 L - \alpha_2 L^2 \qquad \alpha_1 > 0,\ \alpha_2 > 0 \tag{1}$$

As it will become apparent, a quadratic utility function is necessary to preserve the concavity of the Hamiltonian in the optimal control problem.

Under competitive conditions, labour demand has the following linear specification:

$$w = \alpha_1 - 2\alpha_2 L \tag{2}$$

where w is the real wage.

Given (2), the dynamic law which describes the employment evolution is the following:

$$\dot{L} = \theta \left(\frac{\alpha_1 - w}{2\alpha_2} - L \right) \tag{3}$$

where θ is an attrition parameter.

Obviously, the stationary locus for L, *i.e.*, the pairs (L, w) such that $\dot{L} = 0$, is downward sloped.

In the remainder of the paper, we will make the convenient assumption that

$$\alpha_1 = 1 + 2\alpha_2 \tag{4}$$

Given an inelastic labour supply L^S normalised to unity in each period, (4) suggests that the real wage that clears the labour market is equal to 1. Obviously, $u = 1 - L$ provides the corresponding rate of unemployment. See figure 1.

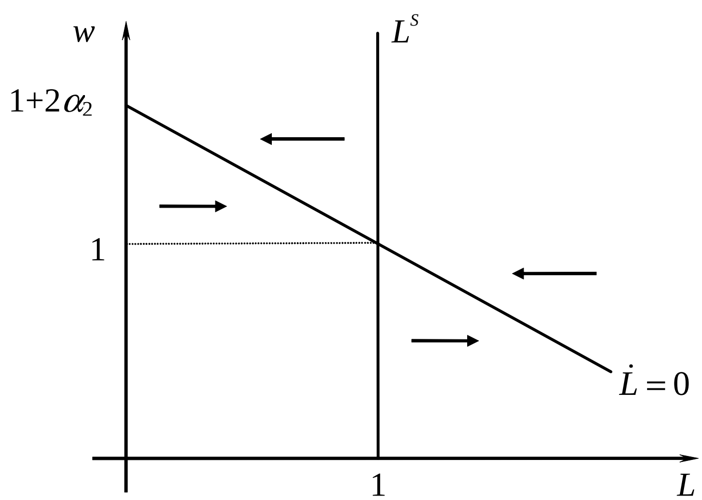

Figure 1: The stationary locus for employment

2.2 Wage Bargaining as an Optimal Control Problem

A distinguishing feature of the present contribution is that w is continuously set by an omniscient arbitrator by following the principles of the optimal control theory[4]. In other words, we interpret the stationary solution of the dynamic system made up of the control variable (the wage) and the state variable (the employment) that results from a well-specified optimal control problem as the *potential* outcome of the bargaining process[5].

The first step of this theoretical exercise is the definition of the instantaneous preferences of the objective arbitrator that is called in to resolve the dispute between the workers and the firm. Given our purposes, a sensible choice is certainly a (linear) weighted average between the net gain of the union (U) and the net gain of the representative employer (π). Therefore, the real wage is assumed to be set through the continuous maximisation of the following expression:

$$\Omega \equiv \gamma\pi + (1-\gamma)\,U \qquad\qquad 0<\gamma<1 \tag{5}$$

where γ represents the relative bargaining strength of the firm.

The linear bargaining solution in (7) is useful in order to preserve analytical tractability. Moreover, it allows for the same comparative statics results for a change in γ as would be obtained in more conventional bargaining solutions[6].

The net gains of the two parties are represented in a conventional way, *i.e.*,

$$\pi = (1+2\alpha_2 - w)\,L - \alpha_2 L^2 \;\text{ and }\; U = L\,(u(w)-u(b)) \tag{6}$$

where $u(\cdot)$ is the utility function of the individual worker and b is its reservation wage.

The reading of the expressions in (6) is straightforward. On the one hand, the net gain for the firm is given by the level of profits in real terms. On the other hand, the net gain for the union is given by the expected utility of its representative member[7].

Given (5) and (6), our optimal control problem becomes the following:

[4]See Koopmans (1965).

[5]As it will become apparent, some stationary solutions may be not feasible bargaining outcomes.

[6]See Lockwood and Manning (1989).

[7]The expressions in (6) suggest that the outside option of the bargaining is zero for the firm and $u(b)$ for the union. Moreover, we are implicitly assuming that *all* the labour force is unionised.

$$
\begin{gathered}
\max_{w} \int_{0}^{+\infty} e^{-\rho t} \left(\gamma \pi + (1-\gamma) U \ \right) dt \\
\overset{s.to}{\dot{L} = \theta \left(\frac{1+2\alpha_2 - w}{2\alpha_2} - L \right)}
\end{gathered}
\tag{7}
$$

where ρ is the rate of time preferences of the arbitrator.

Notice that whenever $\gamma = 0$ our framework provides a version of the monopoly union model.

The current-value Hamiltonian is given by

$$
H = \Omega + \Lambda \theta \left(\frac{1+2\alpha_2 - w}{2\alpha_2} - L \right) \tag{8}
$$

where Λ is the costate variable.

The f.o.c. for w is the following:

$$
(1-\gamma) L u'(w) = \gamma L + \Lambda \frac{\theta}{2\alpha_2} \tag{9}
$$

The result in (9) suggests that in each instant the real wage will be set by equalising the proportional marginal benefit of the union to the proportional marginal benefit of the firm *augmented* by shadow-value of the employment variation. Obviously, each marginal benefit is weighted by the respective bargaining strength of the two parties.

Along the optimal path, Λ has to satisfy the following differential equation:

$$
\dot{\Lambda} = \Lambda (\rho + \theta) - \Omega_L \tag{10}
$$

where $\Omega_L = \frac{\partial \Omega}{\partial L}$.

By exploiting the results in (9) and (10) it is possible to derive a non-linear law of motion for the real wage, *i.e.*,

$$
\dot{w} = \frac{2\alpha_2 \Phi \left(L(\rho + \theta) - \dot{L} \right) - \theta \Omega_L}{2\alpha_2 (1-\gamma) u''(w) L} \tag{11}
$$

where $\Phi = \frac{\partial \Omega}{\partial w} \frac{1}{L}$.

Notice that whenever the firm has all the bargaining power, *i.e.*, $\gamma = 1$, or the workers are risk-neutral, *i.e.*, $u''(w) = 0$, (11) implies an explosive dynamics for w. Moreover, notice that employment dynamics spill over into real wage dynamics[8].

Finally, the transversality condition is the following:

$$\lim_{t \to +\infty} e^{-\rho t} \Lambda(t) L(t) = 0 \tag{12}$$

2.2.1 Steady-State

On the one hand, the equality $\dot{L} = 0$ implies that

$$w = 1 + 2\alpha_2 (1 - L) \tag{13}$$

On the other hand, $\dot{w} = 0$ implies that

$$2\alpha_2 \Phi \left(L(\rho + \theta) - \dot{L} \right) = \theta \Omega_L \tag{14}$$

Given the definitions of Φ and Ω_L, (13) can be substituted in (14) to yield a function which depends only on L, *i.e.*,

$$((1-\gamma) u'(1 + 2\alpha_2 (1-L)) - \gamma) L = \frac{\theta(1-\gamma)}{2\alpha_2(\rho+\theta)} (u(1 + 2\alpha_2(1-L)) - u(b)) \tag{15}$$

By assuming that workers are risk-averse, *i.e.*, $u(w) = w^\beta$, with $0 < \beta < 1$, (15) can be written as

$$\left((1-\gamma)\beta(1 + 2\alpha_2(1-L))^{\beta-1} - \gamma\right) L = \frac{\theta(1-\gamma)}{2\alpha_2(\rho+\theta)} \left((1 + 2\alpha_2(1-L))^\beta - b^\beta\right) \tag{16}$$

Notice that the expression on the left-hand side of (16) is a parabolic function with two real roots, *i.e.*, 0 and $\left(2\alpha_2 - \left(\frac{(1-\gamma)\beta}{\gamma}\right)^{\frac{1}{1-\beta}} + 1\right) / 2\alpha_2$ whose derivative is positive for $L \geqslant 0$. By contrast, the expression on the right-hand side is a decreasing monotonic function with a positive intercept given by $\theta(1-\gamma)\left((1+2\alpha_2)^\beta - b^\beta\right)/2\alpha_2(\rho+\theta)$. Therefore, we may conclude that it exists a positive meaningful stationary solution (L^*, w^*). A graphical outlook is given in figure 2.

[8] As suggested by Lockwood and Manning (1989), "*if wages are determined by collective bargaining period by period, we might expect the time path of wages to be affected by the employment path chosen by the employer*".

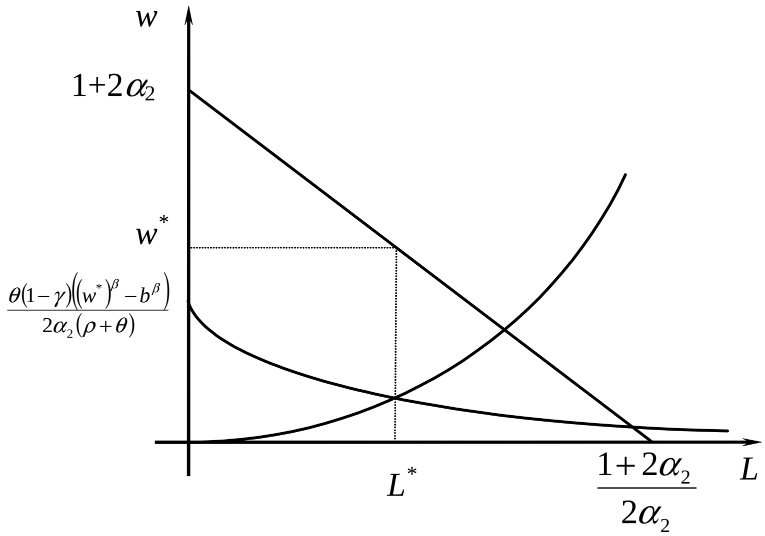

Figure 2: The steady-state

2.2.2 Local Dynamics

By assuming that workers are risk-averse, *i.e.* $u(w) = w^{\beta}$, $0 < \beta < 1$, the linear expansion of our dynamic system around a generic stationary solution (L^*, w^*) is the following:

$$\begin{pmatrix} \dot{w} \\ \dot{L} \end{pmatrix} = \begin{bmatrix} j_{1,1} & j_{1,2} \\ -\frac{\theta}{2\alpha_2} & -\theta \end{bmatrix} \begin{pmatrix} w - w^* \\ L - L^* \end{pmatrix} \tag{17}$$

where:

$$j_{1,1} = \frac{(\rho+\theta)\left((1-\gamma)(1-\beta)\beta + (\beta-2)\Phi^*(w^*)^{1-\beta}\right)}{(1-\gamma)(1-\beta)\beta} + \frac{\theta\left((w^*)^{\beta} - b^{\beta}\right)(2-\beta)}{2\alpha_2(1-\beta)\beta L^*(w^*)^{1-\beta}} \tag{18}$$

$$j_{1,2} = -\frac{\theta\Phi^*(w^*)^{2-\beta}}{(1-\gamma)(1-\beta)\beta L^*} - \frac{\theta(w^*)^{2-\beta}\left(2\alpha_2\gamma L^* + (1-\gamma)\left((w^*)^{\beta} - b^{\beta}\right)\right)}{2\alpha_2(1-\gamma)(1-\beta)\beta(L^*)^2} \tag{19}$$

Given the sign of the elements of the Jacobian matrix in (17), it can be shown that the stationary solution (L^*, w^*) is represented by a saddle point. This means that there will be only one trajectory that satisfies (3) and (11) which converges to the steady-state while all the others diverge. In other words, in our bargaining model the equilibrium path is locally determinate, *i.e.*, there will be a unique w_0 in the neighborhood of w^* that generates a trajectory converging to (L^*, w^*). This value of w_0 should be selected in order to satisfy the tranversality condition in (12) and it will place the system on the stable branch of the saddle point (L^*, w^*).

Moreover, given that $j_{1,1} > 0$ and $j_{1,2} < 0$ the slope of stationary locus for w, *i.e.*, the pair (L, w) such that $\dot{w} = 0$, satisfies - at least in the neighborhood of the steady-state - what Solow and Stiglitz (1968, pg. 547) call the "*natural presumption*" about real wage bargaining. Specifically, the sign of the elements in (18) and (19) show that the $\dot{w} = 0$ locus crosses the $\dot{L} = 0$ locus with a positive slope. This means that in the neighborhood of (L^*, w^*) a higher value of w is consistent with a stable real wage only at a lower unemployment rate.

2.3 Some Numerical Examples

In order to have a better understanding of the model's local dynamics and confirm the analytical results derived above, we carry out some numerical simulations[9]. Specifically, by using the configuration of parameters described in Appendix, we calculate the stationary solution of our dynamic system and the characteristic roots of the Jacobian matrix in (17) for different values of γ. Some results are collected in table 1.

γ	L^*	w^*	r_1	r_2
0.00	0.4395	1.5605	0.8609	−0.9506
0.05	0.4555	1.5445	0.8283	−0.9109
0.10	0.4735	1.5265	0.7973	−0.8668
0.15	0.4965	1.5035	0.7579	−0.8179
0.20	0.5245	1.4755	0.7158	−0.7632
0.25	0.5595	1.4405	0.6703	−0.7019
0.30	0.6065	1.3935	0.6153	−0.6329
0.35	0.6695	1.3305	0.5553	−0.5550
0.40	0.7615	1.2385	0.4830	−0.4673
0.45	0.9035	1.0965	0.3978	−0.3699
0.50	1.1415	0.8585	0.2931	−0.2678

Table 1: Numerical Simulations

[9]The MATLAB 6.5 code used in this paper is available from the author upon request.

The results in table 1 suggests some straightforward conclusions. First, lower values of γ leads to higher values of the wage and the unemployment rate. This result is in perfect consonance with the standard (static) right-to-manage model. However, if the firm becomes too strong our model may deliver bargaining solutions which are not plausible because they imply a value of the real wage lower than the union's outside option that we assumed to equal the workers' reservation wage[10]. Specifically, if we set $b = 1$, then the wage outcome of the bargaining process *cannot* be lower of the full employment retribution[11]. By using the configuration of parameters described in Appendix, this is what happens when the firm and the union have the same bargaining strength[12].

Moreover, each stationary solution (L^*, w^*) is characterised by two real eigenvalues of opposite sign. Obviously, this confirms that in the neighbourhood of the steady-state there is a saddle path. This path is the only one the satisfies the transversality condition in (12) and guarantees the non-negativity of L and w.

Finally, the value of the (negative) convergent root is a decreasing function of the bargaining strength of the firm. This result suggests that trade unions may speed up the adjustment to equilibrium[13]. The same counter-evident conclusion is reached in the dynamic programming right-to-manage model proposed by Lockwood and Manning (1989).

2.4 The Dynamic Model *versus* the Static Model

Before concluding, it may be of some interest to make a comparison between the wage-employment outcomes of our dynamic model and a companion static model that exploits the same linear bargaining solution and the same labour demand. Specifically, we may be interested in comparing the results collected in table 1 with the solutions of the following problem:

$$\begin{gathered} \max_w \gamma \left(\left(1 + 2\alpha_2 - w\right) L - \alpha_2 L^2 \right) + \left(1 - \gamma\right) L \left(w^\beta - b^\beta \right) \\ {\scriptstyle s.to} \\ w = 1 + 2\alpha_2 \left(1 - L\right) \end{gathered} \tag{20}$$

The f.o.c. for w is given by

[10] This result is due to the linear bargaining solution adopted in (5).

[11] In their dynamic programming version of the right-to-manage model, Lockwood and Manning (1989) obtain the competitive outcome for $\gamma \geqslant \frac{1}{2}$.

[12] Moreover, notice that the monopoly union version of our model ($\gamma = 0$) does not provide a bargaining solution below the firm's outside option ($\pi = 0$).

[13] At the steady-state, the stable arm of the saddle-path corresponds to the negative eigenvalues of the linearised system. See Barro and Sala-i-Martin (2004).

$$\left(\frac{1+2\alpha_2-w_s^*}{2\alpha_2}\right)\beta\left(w_s^*\right)^{\beta-1}-\frac{\left(w_s^*\right)^{\beta}-b^{\beta}}{2\alpha_2}=\frac{\gamma}{1-\gamma}\left(\frac{1+2\alpha_2-w_s^*}{2\alpha_2}\right) \tag{21}$$

By using the configuration of parameters descrived in Appendix, we calculate some optimal pair (L_s^*, w_s^*) for different values of γ. The results are collected in table 2.

γ	L_s^*	w_s^*
0.00	0.5045	1.4955
0.05	0.5205	1.4795
0.10	0.5385	1.4615
0.15	0.5605	1.4395
0.20	0.5875	1.4125
0.25	0.6215	1.3785
0.30	0.6655	1.3345
0.35	0.7235	1.2765
0.40	0.8045	1.1955
0.45	0.9225	1.0775
0.50	1.1095	0.8905

Table 2: The static model

A straightforward comparison between the results in tables 1 and 2 suggests that the static model may understate the distortions caused by wage bargaining. In fact, for the same values of γ, the static model predicts unemployment rates that are systematically higher than the ones predicted by the dynamic model. This conclusion is consistent with the "*special case*" monopoly union model developed by Kidd and Oswald (1987) in which trade union membership always equals employment[14].

3 Concluding Remarks

This paper aimed at building a dynamic model in which wage bargaining were represented as a continuous process in an optimal control problem. This task has been carried out by deriving a dynamic version of the right-to-manage model in which an infinitely-lived

[14] More in general, this result follows from the fact that unemployed workers are given no weight in the mediator's objective function.

omniscient arbitrator continuously chooses the real wage rate by tacking into account that employment adjusts towards labour demand.

Our theoretical proposal allowed for a straightforward derivation of a dynamic law for the real wage rate which imposed some interesting restrictions to the model. Specifically, we found that if the union has no bargaining power and/or workers are risk-neutral, the rules of optimal control deliver an explosive dynamics for the real wage. Moreover, our framework allowed for a sharp analysis of the stationary solution and local dynamics of the employment and the real wage. Specifically, under quite general conditions, our model displayed a unique stationary solution characterised by a determined equilibrium trajectory. Furthermore, in the neighbourhood of the steady-state, our dynamic law for real wages verified the Solow and Stiglitz's (1968) "*natural presumption*" on real wage bargaining.

Finally, by resorting to some numerical simulations, we shown that in our framework unions may enhance the adjustment to equilibrium and that standard static models of bargaining may understate the distortions implied by dynamic wage negotiations[15].

The results collected in this paper have to be though as very preliminary. By following Solow and Stiglitz (1968), an interesting theoretical development should be the concern of an employment dynamics that arises from the goods market rationing. As in the present contribution, aggregate supply may derived from the standard profit-maximising behaviour assumption. By contrast, aggregate demand could be obtained by resorting to the Cambridge theory of distribution. Therefore, aggregate spending would result in depending on the different propensities to save and spend wage incomes and profits[16]. Moreover, some interesting insights on the dynamics of wage and employment could derive by allowing the bargaining power of the firm and the union to depend on the employment level. Finally, high-frequency empirical evidence could be used in order to obtain additional understandings on the data-generating process of the wage-employment trajectories. This will be done in later work.

[15]There is another intriguing result that may be proved through simulation, *i.e.*, the non-univocal effect played the mediator's rate of time preferences. Specifically, it may be shown that a more impatient mediator tends to favour the party with the highest bargaining power.

[16]See Kaldor (1955-1956).

4 Appendix

4.1 The Parametrisation of the Model

The numerical simulations in Sections 2.3−4 are carried out by using the set of parameters in table 3.

Parameter	Description	Value
α_2	*productivity parameter*	0.5
θ	*labour market attrition*	0.1
ρ	*discount rate*	0.03
b	*reservation wage*	1
β	*risk-aversion parameter*	0.9

Table 3: The parameters of the model

The productivity parameter has been chosen in order to have $Y'(L) > 0$, $\forall L \in [0, 2)$. Moreover, the labour market attrition and the value of the discount rate are parametrised as in Giammarioli (2003). Finally, recent evidence on workers' risk aversion and union membership may be found in Goerke and Pannenberg (2007).

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