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Abstract

We charaterise the socially optimal mix of firms in an oligopoly with both profit-seeking and labour-managed firms. The policy maker faces a twofold externality: (i) production entails the exploitation of a common pool natural resource and (ii) production/consumption pollutes the environment. We study the relationship between firms' mix and social welfare in the Cournot-Nash equilibrium of the industry and the resulting policy implications.

JEL Codes: L13, H23, P13, Q50

Keywords: mixed oligopoly, pollution, resource extraction

1 Introduction

In this paper, we investigate an industry featuring resource extraction and polluting emissions. Producers are of two types: conventional profit-seeking firms and labour-managed firms, sometimes called cooperatives or workers' enterprises. Hence, we deal with a *mixed* oligopoly as firms pursue different goals. One interest of this perspective lies in the fact that, being the maximization of value added per member/worker a labour-managed firm's objective, the resulting output contraction has a socially desirable impact on the preservation of natural resources and polluting emissions.

We derive the Cournot-Nash equilibrium of such an industry when firms' environmental impact is unregulated. i.e., we assume away any taxation on polluting emission, environmental standards and the like. Standard policy instruments being absent, the policy maker may alter the Cournot-Nash equilibrium and the associated welfare by manoeuvring the access to the industry and/or the composition of the population of firms. If market size is large enough, We show that it is socially optimal to implement a mixed composition in which at least one firm is labour-managed, and this holds for any number of firms and level of fixed costs. Since the environmental impact of firms is twofold, we explore the possibility of regulating access by focussing on the bearings of competition on the balance between resource extraction and the environmental damage. This involves assessing the interplay betwen the standard price effect associated with producer and consumer surplus, on the one hand, and an external effect made of two components, on the other. Since fixed costs may be thought of as a production license, then we prove that the policy maker may set the value of such a license in such a way that the mixed oligopoly maximising social welfare entails the presence of at least two firms and ensures the maximization of the balance between the residual stock and the environmental damage.

Our paper nests into a comparatively small literature investigating simultaneously the impact of production/consumption on resource extraction and polluting emissions (Markusen, 1975; Tahvonen, 1991; Xepapadeas, 1995), where, however, all firms are taken to be profit-maximising agents. This stream of literature, in turn, falls into the broader discussion on the tragegy of commons pioneered by the seminal papers of Gordon (1954, 1967) and Hardin (1968). Another stream of literature our paper is related to is the one on oligopolistic industries formed by profit-seekers exploiting common pool resources.[1]

Our contribution bridges also the debate on the commons with the extant theoretical research on mixed oligopolies formed by profit-seeking and labour-managed firms (see Horowitz, 1991; Cremer and Cremer, 1992; and Delbono and Rossini, 1992, *inter alia*). The by now large literature on such mixed oligopolies concentrates on the nature of strategic interaction between firms with different maximands and its consequences on industry output, price and the resulting surplus, ignoring any environmental consequence. This omission is quite surprising also because we witness a resurgence of interest on cooperatives. Their performance has been scrutinised during the long slum and the empirical research seem to support the view that they perform better than conventional firms as far as employment and survival rates are concerned (for an excellent survey, see Perotin, 2012). The growing interest on environmental topics nowithstanding, the current debate on cooperatives seems to ignore completely the environmental implications of labour-managed firms' objectives. Such implications might be significant given the relevant presence of cooperatives in many Western industries, as plywood in the US, food, construction and manifacturing in Italy and Spain,

[1]See, among others, Cornes and Sandler (1983), Cornes, Mason and Sandler (1986), Mason, Sandler and Cornes (1988) and Mason and Polasky (1994, 1997). For a survey of this literature, see Lambertini (2013).

banking and insurance in Canada, UK and Northern Europe.

The remainder of the paper is structured as follows. Section 2 presents the setup and the preliminary equilibrium analysis of the industry. Section 3 characterises the optimal misture of firms for a given number of firms. Section 4 deals with the optimal access to the industry. Concluding remarks are in section 5.

2 Setup and equilibrium analysis

We consider an oligopolistic market formed by $\mathcal{N} = 1, 2, 3, ...n$ firms selling a homogeneous good produced with the same technology $q_i = l_i$, where q_i denotes i's output and l_i is the amount of labour employed by firm i. The inverse market demand function is

$$p = a - Q,\ Q = \sum_{i=1}^{n} q_i \tag{1}$$

For the moment, we assume any environmental regulation away. Firms are different in their objective function. $m \in (1, n)$ are labour-managed firms (LM) maximising value-added per worker/member:[2]

$$v_i = \frac{pq_i - k}{l_i} = \frac{pq_i - k}{q_i},\ i = 1, 2, 3, ...m \tag{2}$$

where $k > 0$ is a fixed cost. The remaining $n - m$ firms are profit-seeking, maximising

$$\pi_j = (p - w)q_j - k,\ j = m + 1, m + 2, ...n \tag{3}$$

where $w \in (0, a)$ is the unit wage.

Production entails the exploitation of a common pool natural resource whose initial stock is $\overline{X} > 0$, with a one-to-one conversion from the resource

[2] We are focussing on *pure LM* firms, where all workers are also members and conversely. This is a fairly reasonable assumption, as, for instance, the average value of the ratio between members and workers is about 0.7 in Italian production co-ops.

to the final good, in such a way that the residual amount of the resource is $X = \overline{X} - Q$. Moreover, production and/or consumption pollute the environment via CO_2-equivalent emissions $E = Q$, resulting in a convex environmental damage $D = bE^2 = bQ^2$, $b > 0$. Accordingly, the social welfare function is

$$SW = \sum_{i=1}^{n} \pi_i + CS + X - D \tag{4}$$

where $CS = Q^2/2$ is consumer surplus. Notice that total producer surplus is accounted for by profits irrespective of the actual maximand of a subset of firms pursuing another goal.[3] In the present setting, the profits of an LM firm are

$$\pi_i = (p - v_i)\, q_i - k \tag{5}$$

The solution concept of this oligopolistic game is the one-shot Cournot-Nash equilibrium. The first order conditions (FOCs) for LM and profit-seeking units, respectively, are

$$\frac{\partial v_i}{\partial q_i} = \frac{k}{q_i^2} - 1 = 0 \tag{6}$$

$$\frac{\partial \pi_j}{\partial q_i} = a - 2q_j - Q_{-j} - w = 0 \tag{7}$$

in which $Q_{-j} = \sum_{i=1}^{m} q_i + \sum_{h \neq j} q_h$. Now, imposing symmetry across individual outputs within groups of firms and solving the simultaneous system (6-7), one obtains the equilibrium outputs

$$q_{LM}^{CN} = \sqrt{k}\,;\; q_{\pi}^{CN} = \frac{a - w - m\sqrt{k}}{n - m + 1} \tag{8}$$

where superscript CN mnemonics for *Cournot-Nash*. At the CN equilibrium, the maximised objective functions amount, respectively, to:

$$v_{LM}^{CN} = \frac{a + w\,(n-m) - \sqrt{k}\left[m^2 + (n+1)\,(n - 2\,(m-1))\right]}{n - m + 1} \tag{9}$$

[3] Alternatively, one might take the presence of cooperatives literally and embed their goal v_i as such in the producer surplus and therefore also in the social welfare function. This seems the approach suggested by Dow (2003).

$$\pi_{\pi}^{CN} = \frac{k\left[m^3 + (n+1)(m-1)(n-2m-1)\right] + (a-w)\left[a-w-\sqrt{k}\Upsilon\right]}{(n-m+1)^2} \tag{10}$$

where $\Upsilon \equiv 2n + 1 + (n-m)^2$.

Before delving into the details of the mixed oligopoly we are looking at, it is worth characterising the properties of the two polar cases in which all firms are, alternatively, profit-seeking or LM enterprises.

2.1 All firms are profit-seekers

Here, $m = 0$. If so, we are facing a traditional Cournot game with increasing returns to scale in which individual output is $q_{\pi}^{CN}(m=0) = (a-w)/(n+1)$ and equilibrium profits are

$$\pi_{\pi}^{CN}(m=0) = \frac{(a-w)^2}{(n+1)^2} - k \geq 0 \; \forall \; k \in \left(0, \frac{(a-w)^2}{(n+1)^2}\right) \tag{11}$$

and consumer surplus is $CS_{\pi}^{CN}(m=0) = n^2(a-w)^2/\left[2(n+1)^2\right]$, while the resulting amount of residual resource and environmental damage are $X_{\pi}^{CN}(m=0) = \overline{X} - n(a-w)/(n+1)$ and $D = bn^2(a-w)^2/(n+1)^2$.

2.2 All firms are LM

Here, $m = n$. If so, individual output is $q_{LM}^{CN}(m=n) = \sqrt{k}$ and consumer surplus is $CS_{LM}^{CN}(m=n) = n^2k/2$. As for the residual resource and the environmental damage, we have $X_{LM}^{CN}(m=n) = \overline{X} - n\sqrt{k}$ and $D = bn^2k$.

Since

$$q_{\pi}^{CN}(m=0) - q_{LM}^{CN}(m=n) = \frac{a-w+(n+1)\sqrt{k}}{n+1} > 0 \tag{12}$$

which in turn implies $\pi_{\pi}^{CN}(m=0) > \pi_{LM}^{CN}(m=n)$. Hence, we can claim what follows:

Lemma 1 *For any given $n \geq 1$, a profit-seeking industry yields higher profits and consumer surplus than an LM industry. However, it depletes the resource and pollutes more than an LM industry.*

Therefore, there exists a tradeoff between the price effect determining the volume of profits and consumer surplus and the external effect associated with resource extraction and the emissions generated by production/consumption. The first effect speaks in favour of profit-seeking behaviour, while the second one supports the adoption of firms' goals leading to output restrictions, as it is the case with LM firms. This tradeoff triggers the analysis we are about to illustrate.

3 The optimal mix of firms in the industry

We are back into the mixed case where $m \in (1, n)$. At the Cournot-Nash equilibrium $\left(q_{LM}^{CN}, q_{\pi}^{CN}\right)$ social welfare (4) is

$$SW^{CN} = \frac{(n-m)\left[a-(n+1)\sqrt{k}-w\right]\left[a+(n+1-2m)\sqrt{k}\right]}{(n-m+1)^2} - m\sqrt{k} + \overline{X}$$
$$+\frac{(1-2b)\left[n(a-w)-m\left(a-\sqrt{k}-w\right)\right]^2}{2(n-m+1)^2} - \frac{(n-m)\left(a-m\sqrt{k}-w\right)}{n-m+1} \tag{13}$$

Taking n as given, we now focus on the socially optimal distribution of firms across groups. That is, what is the partition among LM and profit-seekers that maximises SW^{CN}? Putting aside the integer problem, and treating n and m as continuous variables, the answer comes from the solution of the following FOC:

$$\frac{\partial SW^{CN}}{\partial m} = \frac{\Psi\left[\Phi + \left(m(n+2(1+b)) - (n+1)^2\right)\sqrt{k} - (a-w)\Omega\right]}{(n-m+1)^2} = 0 \tag{14}$$

where $\Psi \equiv a-(n+1)\sqrt{k}-w$, $\Phi \equiv n-m+1$ and $\Omega \equiv 1-2b(n-m)$. The unique solution to (14) is

$$m_{SW} = \frac{(a-w)(2bn-1)+(n+1)\left[1+(n+1)\sqrt{k}\right]}{2b\left(a-w-\sqrt{k}\right)+1-(n+2)\sqrt{k}} \tag{15}$$

In m_{SW}, the second order condition writes

$$\frac{\partial^2 SW^{CN}}{\partial m^2} = -\frac{\left[(n+2(1+b))\sqrt{k}-1-2b(a-w)\right]^4}{(1+2b)^3\,\Psi^2} \tag{16}$$

which is strictly negative everywhere.

The last step consists in studying the properties of solution (15). For m_{SW} to be economically meaningful, the following constraints should be met:

[1] $m_{SW} \in [1,n]$: at least one firm must be an LM.

[2] $v_{LM}^{CN}\big|_{m_{SW}} \geq w$: this amounts to requiring that the value added be at least as great as market wage because otherwise workers would quit LM firms and sell their labour elsewhere.

[3] $q_{LM}^{CN}\big|_{m_{SW}} > 0$: the equilibrium output of LM firm(s) must be positive.

To begin with, for the sake of simplicity, we define market size as $A \equiv a-w > 0$. Then, constraint **[1]** requires the simultaneous satisfaction of

$$n-m_{SW} = \frac{A+(1-2nb)\sqrt{k}+1}{2b\left(A-\sqrt{k}\right)+1-(n+2)\sqrt{k}} \geq 0 \tag{17}$$

and

$$m_{SW}-1 = \frac{A\left[1-2b(n-1)\right]-n-\left[1+2b-n(n+1)\right]\sqrt{k}}{2b\left(A-\sqrt{k}\right)+1-(n+2)\sqrt{k}} \geq 0. \tag{18}$$

The numerator of $n - m_{SW}$ is non-negative iff

$$A \geq \max\left\{0, (2nb-1)\sqrt{k} + 1 \equiv A_1\right\} \tag{19}$$

The numerator of $m_{SW} - 1$ is non-negative iff

$$A \geq \max\left\{0, \frac{\sqrt{k}\left[n(n+1) - 2b - 1\right] - n}{2b(n-1) - 1} \equiv A_2\right\} \tag{20}$$

The denominator of both is non-negative iff

$$A \geq \max\left\{0, \frac{\sqrt{k}\left[2(1+b) + n\right] - 1}{2b} \equiv A_3\right\} \tag{21}$$

Then, it is easily checked that **[2-3]** are met if A satisfies (21). Consequently, we are left with three conditions on market size A, implying

Proposition 2 *If* $A > \max\{0, A_1, A_2, A_3\}$, *then* $m_{SW} \in (1, n)$.

Moreover, A_1, A_2 and A_3 intersect each other, for any given pair (k, n), in correspondence of

$$b = \frac{(n+2)\sqrt{k} - 1}{2n\sqrt{k}} \equiv \widehat{b} > 0 \tag{22}$$

for all $k > 1/(n+1)^2$ and conversely. This immediately implies:

Corollary 3 *For all* $k \in \left(0, 1/(n+1)^2\right]$, $\widehat{b} \leq 0$ *and therefore*

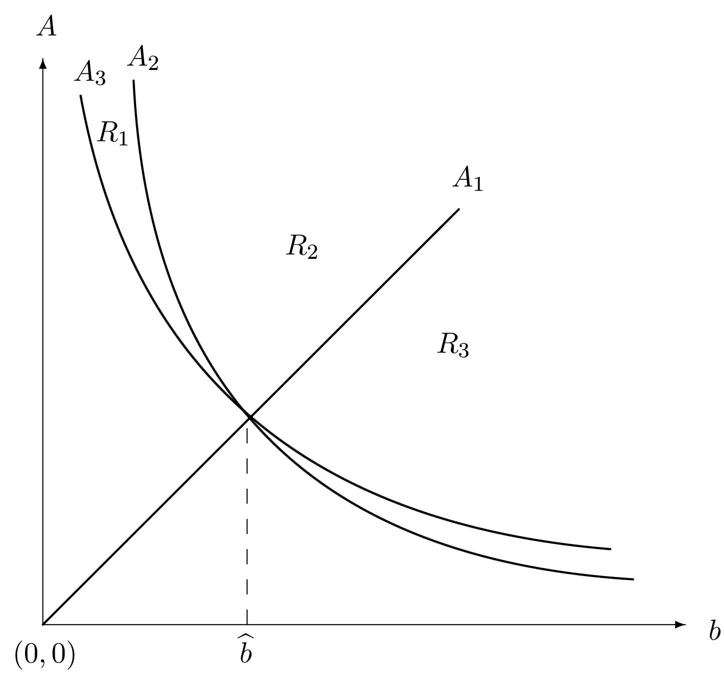
$$\max\{0, A_1, A_2, A_3\} = A_1.$$

Consequently, it is socially inefficient to have all firms adopting a profit-maximising behaviour.

The intuitive explanation of this Corollary is that if the fixed cost is sufficiently low, entry becomes more profitable and the associated industry output expansion implies more pressure on the natural resource and a higher environmental damage. On the other hand, for the LM firms, a low fixed cost shrinks individual and industry output and therefore reduces their impact on the resource and the environment. As a consequence, for small levels of k, the socially optimal composition of the population of firms in the industry is either mixed of entirely LM.

The foregoing discussion can be illustrated graphically in the space (b, A), relating market size to the intensity of the environmental damage. Figure 1(i) portrays the situation in which area R_1 is non-empty, i.e., $k > 1/(n+1)^2$ and therefore $\widehat{b} > 0$.

Figure 1(i) The socially optimal mix of fims when $k > 1/(n+1)^2$



We can identify three regions:

- Region R_1 is defined as the locus $A_1 < A_3 < A < A_2$. Here, $m = 0$, i.e., the socially optimal composition of firms' types collapses in a corner solution where all firms maximise profits.

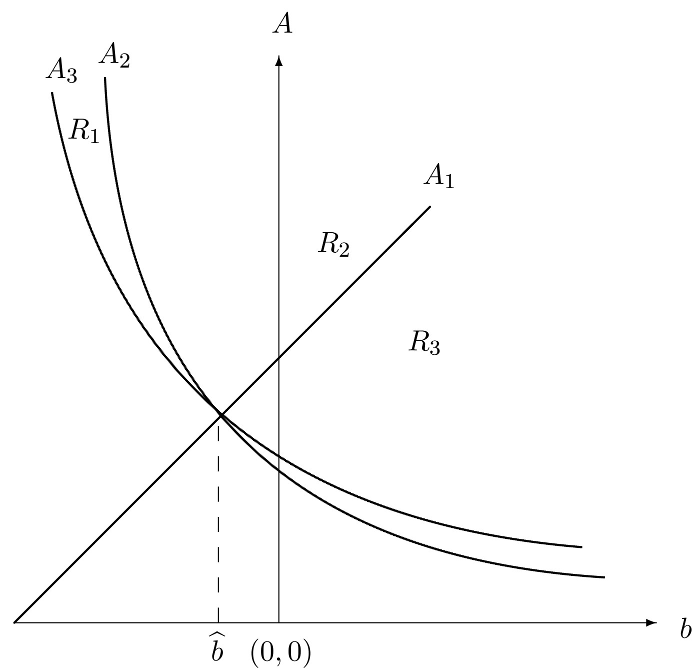
- Region R_2 is the set of all point such that A is above the upper envelope of $\{0, A_1, A_2, A_3\}$. Here, $m \in (1, n)$ and therefore both types of firms have to be active in order to maximise social welfare. This region defines the parameter constellation in which Proposition 2 holds.

- Region R_3 identifies all points such that $A_1 > A > A_3 > A_2$. Here, welfare is maximised by an oligopoly consisting of LM firms only.

We can explain the above spectrum of industry composition on the basis of the balance between a price effect and an external effect. By price effect we mean the standard tradeoff between equilibrium quantity and price along the demand function, which is grasped by the magnitude of market size measured by A. The external effect - which here is measured by the intensity of polluting emissions - is captured by the level of parameter b. Accordingly, region R_1 features a high value of A and a low value of b, which makes profit-seeking firms more welfare-enhancing than LM ones (as the latter produce less). Exactly the opposite argument applies to region R_3. In the intermediate range R_2, the tradeoff between the two effects calls for a mixed population of firms.

Figure 1(ii) depicts the alternative case in which $\widehat{b} < 0$ and therefore only R_2 and R_3 exist in the positive quadrant. This rules out the social desirability of an entirely profit-seeking industry.

Figure 1(ii) The socially optimal mix of fims when $k < 1/(n+1)^2$



One may wonder whether the arising of a mixed oligopoly at the social optimum is robust to any change in fixed cost k and industry structure n. This question amounts to controlling the non-emptiness of R_2 in the positive quadrant (remember that both A and b are strictly positive). Without any additional proof, since $\partial A_1/\partial b > 0$, we may claim:

Proposition 4 *For all* (k, n), *region* R_2 *always exists in the space* (b, A).

In words, the "mixed" solution represents the social optimum irrespective of the magnitude of the fixed cost and the number of firms. More precisely, this is the socially desirable mixture of firms whenever the intensity of the environmental damage is large *vis à vis* the market size. If k is a production license, the above Propositions tells us that policy maker should sell $m_{SW} \geq 1$ licenses to LM firms and $n - m_{SW}$ licenses to profit-seekers, for any $n \geq 2$. There remains to establish the conditions under which indeed both $m_{SW} \geq 1$ and $n \geq 2$ hold, taking into more explicit consideration the explotation of the commons.

4 The optimal number of firms in the commons

So far, we have taken the total number of firms in the industry as given. However, we know from the literature on the optimal access to commons in oligopoly (cf. Cornes and sandler, 1983; Cornes, Mason and Sandler, 1986; and Mason and Polasky, 1997, *inter alia*), that a central issue for the policy maker deals with determining the number of firms allowed to exploit the common pool.

If we tackle this issue within our setting, since we are assuming that the policy maker is maximising SW w.r.t. m, we can envisage a perspective in which the same policy maker wants to maximise $X^{CN} - D^{CN}$ w.r.t. n. In other words, the policy maker simultaneously calculates the social welfare-maximising number of LM firms and the total number of firms maximising the balance between the residual stock and the environmental damage.

The necessary condition is $\partial \left(X^{CN} - D^{CN} \right) / \partial n = 0$, which delivers

$$n = \frac{m \left[1 + 2b \left(A - \sqrt{k} \right) \right] - 1}{1 + 2Ab} \tag{23}$$

If $m = m_{SW}$, the above expression simplifies as follows:

$$n = -\frac{1 + 2b \left(A + \sqrt{k} \right)}{2b\sqrt{k}} \tag{24}$$

which is always negative. Hence, the policy maker cannot do any better than enforcing monopoly. Since $\partial \left(X^{CN} - D^{CN} \right) / \partial n < 0$ for all $n \geq 1$, the only plausible route is to pose an upper limit to the number of firms in such a way that $X^{CN} - D^{CN} \geq 0$ in correspondence of $m = m_{SW}$:

$$X^{CN} - D^{CN}\big|_{m=m_{SW}} = \overline{X} - \frac{\left[1 + b\left(A + 1 + \sqrt{k}\,(n+1)\right)\right]\left[A - 1 + \sqrt{k}\,(n+1)\right]}{(1+2b)^2} \tag{25}$$

The above expression is non-negative for all

$$n \leq \frac{(1+2b)\sqrt{k\left(1 + 4b\overline{X}\right)} - 2bk - \sqrt{k}\,(1 + 2Ab)}{2bk} \equiv \widetilde{n} \tag{26}$$

with $\widetilde{n} > 2$ for all

$$\overline{X} > \max\left\{0, \frac{\left[1 + b\left(A + 1 + 3\sqrt{k}\right)\right]\left(A - 1 + 3\sqrt{k}\right)}{(1+2b)^2}\right\} \tag{27}$$

If k is an entry fee (for instance, a production license), then fixing

$$k \in \left[\frac{(A-1)^2}{9}, \frac{\left[1 + b\,(A+1)\right]^2}{9b^2}\right] \tag{28}$$

ensures

$$\max\left\{0, \frac{\left[1 + b\left(A + 1 + 3\sqrt{k}\right)\right]\left(A - 1 + 3\sqrt{k}\right)}{(1+2b)^2}\right\} = 0 \tag{29}$$

so that indeed $\widetilde{n} > 2$ for all $\overline{X} > 0$. This amounts to saying that the policy maker may always appropriately set the entry cost so as to guarantee the presence of at least two firms in the industry. The foregoing discussion boils down to the following result:

Proposition 5 *There exists a non empty range of k wherein the social welfare is maximised by a mixed oligopoly in which the presence of at least two firms ensures that $X^{CN} - D^{CN} > 0$.*

5 Concluding remarks

In this paper we have charaterised the socially optimal mix of firms in an oligopoly with both profit-seeking and labour-managed firms, whose activity relies on natural resource exploitation and implies polluting emissions. We have left out of the picture traditional environmental regulation instruments, in order to focus on the bearings of industry structure and composition. We have shown that a mixed oligopoly maximises welfare under plausible conditions on market size, irrespective of the number of firms and the level of entry costs. We have also investigated the possibility of regulating access to the industry taking into consideration the balance between common pool exploitation and the environmental damage. In this respect, we have proved that the policy maker may set the value of the fixed cost/license in such a way that the welfare-maximising mixed oligopoly accomodates at least two firms and grants the maximization of the balance between the residual stock and the environmental damage.

Among possible extensions of our line of research, one worth mentioning is the analysis of mixed oligopolies with twofold environmental externality including at least one public enterprise in a population of profit-seekers. This amounts to considering the publicly-owned firm as a regulatory tool internal to the industry, as in Dragone, Lambertini and Palestini (2014), where, however, only polluting emissions are considered.

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