Frugals, Militants and the Oil Market

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Abstract

The oil market has often been modeled as an oligopoly where the strategic players are producers. With climate change, a new sort of game appeared, where environmental militants play a significant role by opposing some projects, to contain oil production. At the same time, consumers continue to use increasing amounts of oil, independently of oil price fluctuations. Should we oppose oil projects, reduce demand or both? We investigate in this paper the double prisoner's dilemma in which individuals find themselves, with respect to oil consumption and their environmental stance towards the oil industry. We find that the collective outcome of such game is clearly better when a frugal behavior is adopted, without being militant. The Nash equilibrium, resulting from the individual strategies, leads by contrast to the worst possible outcome: high prices, high consumption and high environmental (negative) impact. An effective environmental action should avoid opposing oil supply sources (a costly militant act) and help consumers becoming more frugal.

Keywords: *prisonner's dilemma, oil production, militancy, frugality*

1 Introduction

A large consensus exists on the necessity to mitigate climate change. A reduction of CO_2 emissions in needed for this to happen, and as 65% of all greenhouse gases are related to fossil fuel and industrial processesIPCC,2014, fossil fuel consumption has to decline and industrial processes have also to change. Emissions from the combusion of coal and oil are particularly important IEA,2017. But

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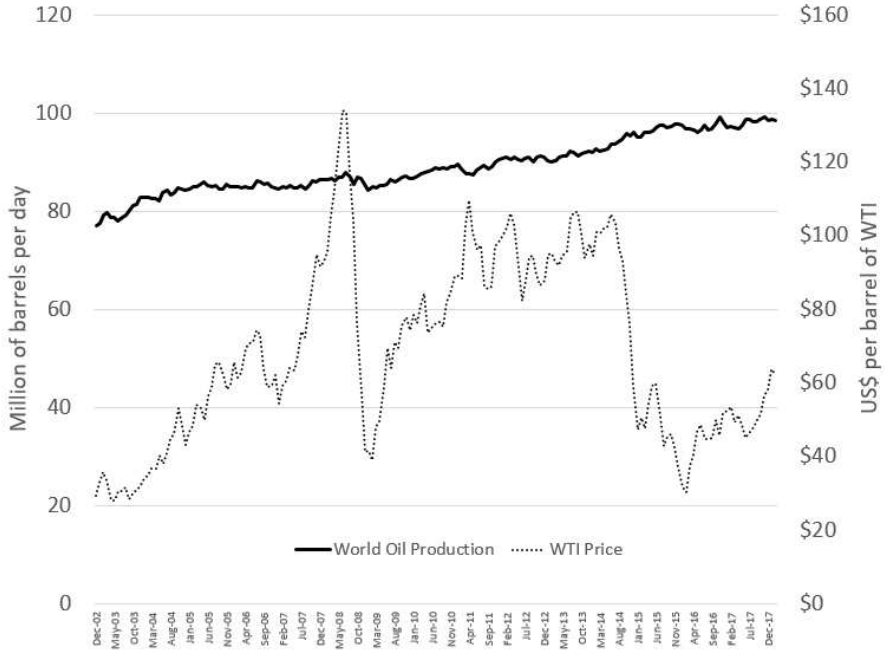
Figure 1: World oil production and price, 2002-2018 EIA,2018

while coal consumption, and coal-related emissions, have peaked in 2014, oil consumption continues to grow. So does oil production, as consumption and production follow each other very closely - with only short term stocks and strategic reserves creating a difference. As illustrated in Figure 1, oil production is on an almost linearly increasing path, from about 80 millions barrels per day in 2002 to close to 100 millions barrels per day in 2018 EIA,2018. Oil prices, perhaps surprisingly, have no apparant impact on consumption and production. Indeed, despite large swings in oil prices in the 2002-2018 period, from $28 to $134 per barrel of Western Texas Intermediate (WTI), oil demand and production continued their steady growth. This translates in very inelastic measures of the price elasticity of oil and oil products demands (usually around -0.2), as many econometric studies conclude. See for instance Labandeira,2017.



While high oil prices have not discouraged consumers to use oil, environmental militants have been very active to oppose oil projects. Movements such as *Keep It in the Ground* try to "revoke the social license of the fossil fuel industry" and "fight iconic battles against fossil fuel infrastructure" 350.org,2018. Their hope is that by opposing oil development, hence by limiting supply, consumption will

go down, and so would emissions. Climate change would consequently be mitigated. Some fossil fuel infrastructure can indeed be abandoned by promoters after a "successful" opposition. In Canada, for instance, strong opposition to some major oil pipeline projects (Energy East and TransMountain) has pushed their promoters to renounce developing them.

Despite such opposition, however, oil consumption has not decreased. It is supply that has been affected: some oil projects are removed from the supply mix, and more expensive ones are selected. While it's impossible to directly link the cancellation of one project to the development of another, one could easily conjecture that when oil investments are not made in, for instance, Alberta (Canada), because of some strong local opposition, it will lead to some equivalent investments made in the United States, Brazil, Iraq or Libya, where oil production can grow and is growing (see for instance IEA,2018, for some current numbers and forecasts). In short, oil production does not decline after some oil project opposition, but marginally more expensive projects, with less opposition, are chosen. See Herfindahl,1967 and the subsequent literature on the order of extraction of an exhaustible resource. Such price increase indirectly makes renewable energy more competitive. However, so far new renewable energy sources (such as wind or solar) are added to the global production mix, especially in electricity generation, but aren't substitute to oil in the transportation sector, where most of the oil is consumed.

In many cases, when environmental militants oppose oil projects, they do not directly call for a lower oil consumption from individuals. Greenpeace International, for instance, asks its website visitors to "Join the wave of resistance against pipelines", but does not advice to use less oil products, to question friends about their vehicule choice or to adopt a frugal energy consumption level (see Greenpeace International,2018). Maybe they assume that displaying "resistance" is more self-satisfying than not, while reducing oil consumption is too individually demanding. Could it therefore be a better strategy to be an environmental militant than to adopt (and possibly promote) a frugal lifestyle? Of course, the two are separate decisions and can be done simultaneously. But given the price inelasticity of oil demand, as illustrated before, supply side strategies of environmental militants may not have the intended results.

This paper belongs to the family of papers dealing with pollution challenges within a game theoretic framework, to which Georges Zaccour has significantly contributed. See for instance Petrosjan and Zaccour (2003), Breton, Sbragia and Zaccour (2010) or Jørgensen, Martín-Herrán and Zaccour (2010), among many

others. Our paper also considers the action of the civil society (or environmental groups) in the absence of a central authority, where strategic choices can be made to the benefit, or detriment, of all, as in Ngendakuriyo and Zaccour (2017), which focuses on corruption. Contrary to these papers, however, we limit ourselves to a static context.

More specifically, this paper attempts to disentangle the different aspects related to our specific situation. Given the two sets of choices mentioned above, being an environmental militant or not and adopting a frugal level of energy consumption or not, what are the invidual and collective outcomes? What are the environmental impacts of these choices, but also the price and welfare impacts?

We offer some answers to these questions, by studying the strategic situations related to the two sets of choices. In both cases, individuals face a prisoner's dilemma: they would be better off with a lower consumption level (because of the global environmental impact) and no opposition to oil projects (because of the lower prices), only if all did the same. But gratification from higher consumption and adopting a militant environmental stance creates incentives to defect.

While we make some simplifying assumptions, notably that oil demand is strictly price-inelastic, our analysis shows that welfare gains come from lower consumption levels. Militancy can be costly and benefit the oil industry in ways that may not be fully understood by oil projects opponents. However, the assumption on price-elasticity is made for the sake of clarity in the exposition, but would not change the main results if relaxed.

We present the model in the next section, the individual strategies and the market equilibirum. Then we investigate the four polar collective outcomes of the game, and compare their price, quantity (equivalent to the environmental impact) and welfare levels.

2 The model

Consider a population with N identical individuals endowed with a utility

$$\mathscr{U}(q, s; p, Q) = v(p, q) + b(s) - e(Q),$$

where $v(p, q)$ stands for the net utility from individual consumption q at price p, $b(s)$ stands for the benefits from environmental stance s and $e(Q)$ for the

individual environmental costs, a function of total consumption Q.

Individual consumption q can be either *average* or *frugal:* $q \in \{a; f\}$. Environmental stance is either *militant* or *not*: $s \in \{m; \emptyset\}$. Collective consumption Q is determined by the interplay of supply and demand.

2.1 The game in individual strategies

Let N be the total number of players and denote by N_f and N_m the number of "frugals" and the number of militants. The market equilibrium depends upon the individual strategies of all players. We denote respectively by $p^* = p(N_f, N_m)$ and $Q^* = Q(N_f, N_m)$ the equilibrium price and quantity outcomes. As we shall see – and as expected – $Q^* = Q(N_f, N_m)$ is non-increasing in both its arguments.

We make the following assumptions:

Assumption 1. *In regard of their environmental impact, individuals find it individually too costly to adopt a frugal behaviour :*

$$\mathscr{U}(f, s, Q(N_f; N_m)) < \mathscr{U}(a, s, Q(N_f - 1; N_m)),$$

for all $N_f \in [\![1; N]\!]$ *and whatever the values of* $s \in \{m; \emptyset\}$ *and* $N_m \in [\![0; N]\!]$.

Assumption 2. *Individuals find it individually profitable to adopt a stance of environmental militant:*

$$\mathscr{U}(q, m, Q(N_f; N_m)) > \mathscr{U}(q, \emptyset, Q(N_f; N_m - 1)),$$

for all $N_m \in [\![1; N]\!]$ *and whatever the values of* $q \in \{a; f\}$ *and* $N_f \in [\![0; N]\!]$.

Assumption 3. *It would be collectively rational to adopt a frugal behaviour:*

$$\mathscr{U}(f, s, Q(N; N_m)) > \mathscr{U}(a, s, Q(0; N_m)),$$

whatever the values of $s \in \{m; \emptyset\}$ *and* $N_m \in [\![0; N]\!]$.

Given these assumptions it is clear that:

Lemma. *The dominant individual strategies are*

$$(q; s) = (a, m).$$

2.2 The market equilibrium

As mentioned in the introduction, demand is pretty insensitive to prices. We assume that total demand D thus depends only upon the number of frugals, so that

$$D(N_f) = q_a(N - N_f) + q_f N_f,$$

where $q_a > q_f$. On the supply side, price matters. Moreover, it is directly impacted by militancy. Again, for simplicity we suppose that:

$$S(p, N_m) = \sup\left\{0; \beta\left[p - \left(\underline{p} + cN_m\right)\right]\right\},$$

where β is the positive slope of the supply curve, $\underline{p}$ is the minimum price at which production can take place with no militancy, and c is the individual impact of militancy on such minimum price.

We assume competitive markets. By definition, at equilibrium $D = S$ so that the equilibrium price is given by

$$\begin{aligned} p(N_f, N_m) &= \underline{p} + cN_m + \beta^{-1}\left[q_a(N - N_f) + q_f N_f\right] \\ &= \underline{p} + \beta^{-1} N q_a - \beta^{-1}(q_a - q_f) N_f + cN_m. \end{aligned} \tag{1}$$

This says that the price increases with the number of militants, N_m, but decreases with the number of frugals, N_f. By contrast, the equilibrium quantity is a function of the number of frugals only:[1]

$$\begin{aligned} Q(N_f, N_m) &= q_a N - (q_a - q_f) N_f, \\ &\equiv Q(N_f). \end{aligned} \tag{2}$$

In words, the number of militants has an impact only on price (hence on consummer welfare) but *not* on equilibrium demand - hence upon the environmental impact.

[1] This is a direct consequence of the assumption on demand *in*elasticity.

2.3 Discussion

2.3.1 Individual cost of militancy

Coming back to Assumption 2 upon the payoff of militancy, we assumed that

$$b(m) - b(\emptyset) > v(p(N_f; N_m - 1), q) - v(p(N_f; N_m), q).$$

Decomposing the net utility into gross utility net of spendings (that is substituting $w(q) - pq$ to $v(p, q)$) this amounts to:

$$b(m) - b(\emptyset) > [p(N_f; N_m) - p(N_f; N_m - 1)] q. \tag{3}$$

This means that the monetary costs (through the price impact) to the consumers of their militancy cannot counterweight the benefits from their environmental stance. This is fully consistent with the (negligible) price inelasticity of their individual demand.

2.3.2 Impact on the oil industry

Yet militancy increases consumer financial burden which directly profits the industry. In fact, for any N_f, hence for any given level of total demand, the industry revenues R are an increasing function of the number of militants:

$$\begin{aligned} R(N_f; N_m) &= p(N_f; N_m) Q(N_f) \\ &= R(N_f; 0) + cN_m Q(N_f), \end{aligned}$$

from equations (1) and (2). Paradoxically, therefore, militancy is beneficial to the oil industry, except of course for those producers who have been excluded from the market. In fact, by reducing total supply, militancy is akin to the action of an oil cartel. The main difference is that the production reduction is not evenly shared by all producers, but obtained by excluding some specific oil production sites.

2.3.3 Social costs of militancy

While the individual costs of militancy is smaller than its individual benefits (see equation (3)), it is also borne by everyone, through the price increase it triggers. We assume that the individual (psychological) benefits from taking a

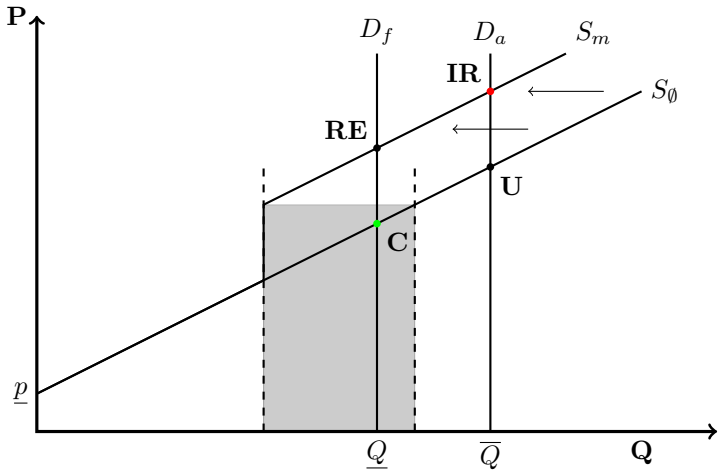


Figure 2: The four polar collective outcomes: Individually rational (**IR**), Unconcerned (**U**), Cooperative (**C**) and Radical environmentalist (**RE**).
When militants manage for the projects associated to the grey area to be cancelled, the subsequent supply curve is shifted to the left.

militant environmental stance are smaller than the financial costs it imposes on all consumers. Formally

Assumption 4. *Individual (psychological) benefits from taking a militant environmental stance are smaller than the financial costs it imposes on all consumers.*

$$b(m) - b(\emptyset) < [p(N_f; N_m) - p(N_f; N_m - 1)] Q(N_f),$$

for any $N_m \geq 1$ *and any* N_f.

3 Collective outcomes

We now consider the collective outcomes of the strategic game. There is a double prisoner's dilemma, one in each of the strategic variables $q \in \{a, f\}$ and $s \in \{m, \emptyset\}$. We identify four polar collective outcomes.

3.1 Four polar collective outcomes

Let $\overline{Q} = q_a N$ and $\underline{Q} = q_f N$.

3.1.1 Individually rational outcome

As already mentioned in Lemma 2.1, it is a dominant strategy for individuals to be an average consumer and a militant. Therefore, the individually rational outcome is $(N_f; N_m) = (0, N)$ and

$$Q^{IR} = \overline{Q}, \qquad p^{IR} = \underline{p} + \beta^{-1}\overline{Q} + cN$$

so that

$$\mathscr{U}^{IR} = w\left(q_a\right) - p^{IR}q_a + b\left(m\right) - e\left(\overline{Q}\right).$$

3.1.2 Cooperative outcome

If players were to cooperate, they would be frugal and abstain from militancy. Therefore, the cooperative outcome is $(N_f; N_m) = (N, 0)$ and

$$Q^{C} = \underline{Q} \qquad p^{C} = \underline{p} + \beta^{-1}\underline{Q}$$

so that

$$\mathscr{U}^{C} = w\left(q_f\right) - p^{C}q_f + b\left(\phi\right) - e\left(\underline{Q}\right).$$

3.1.3 Outcome of an unconcerned population

If consumers are unconcerned so that they all maintain an average consumption and do not bother to take a militant position, the collective outcome is $(N_f; N_m) = (0, 0)$ and

$$Q^{U} = \overline{Q} \qquad p^{U} = \underline{p} + \beta^{-1}\overline{Q}$$

so that

$$\mathscr{U}^{U} = w\left(q_a\right) - p^{U}q_a + b\left(\phi\right) - e\left(\overline{Q}\right).$$

3.1.4 Outcome of a radical environmentalist population

If individuals are all frugal and engaged in militancy, despite its costs, then $(N_f; N_m) = (N, N)$ and

$$Q^{RE} = \underline{Q} \qquad p^{RE} = \underline{p} + \beta^{-1}\underline{Q} + cN$$

so that

$$\mathscr{U}^{RE} = w\left(q_f\right) - p^{RE} q_f + b\left(m\right) - e\left(\underline{Q}\right).$$

3.2 Discussion

3.2.1 Quantity and price comparisons

In terms of quantities, hence environmental impact, the comparison between the four cases is pretty straightforward:

$$Q^{RE} = Q^C = \underline{Q} < \overline{Q} = Q^U = Q^{IR}.$$

There are also simple comparisons between some prices:

$$\begin{aligned} p^{RE} < p^{IR} \qquad &\text{and} \qquad p^C < p^U; \\ p^C < p^{RE} \qquad &\text{and} \qquad p^U < p^{IR}; \end{aligned}$$

Hence $p^C < p^{IR}$. However, the comparison p^{RE} and p^U is *a priori* ambiguous.

The difference between both prices depends upon the elasticity of supply and the difference between the average and frugal demands. More precisely,

$$p^{RE} - p^U = cN - \beta^{-1}\left(Q^U - Q^{RE}\right) = \left[c - \beta^{-1}\left(q_a - q_f\right)\right] N.$$

In words, the price will be higher with a population of **R**adical **E**nvironmentalists than with an **U**nconcerned population if (and only if), the sole impact of their own militancy upon the equilibrium price is sufficient to induce individuals to reduce their demand by a larger amount than that associated to shifting from average to frugal consumption. In all other cases, that is when

$$\beta c < q_a - q_f, \tag{4}$$

we have $p^{RE} < p^U$. It is thus fair to assume that

$$p^C < p^{RE} \leq p^U < p^{IR}.$$

3.2.2 Welfare comparisons

In terms of welfare, the pairwise comparison of the four polar outcomes is less straightforward. We have

$$\begin{aligned}\mathscr{U}^{IR}-\mathscr{U}^{RE} &= \left[w\left(q_a\right)-p^{IR}q_a+b\left(m\right)-e\left(\overline{Q}\right)\right]-\left[w\left(q_f\right)-p^{RE}q_f+b\left(m\right)-e\left(\underline{Q}\right)\right]\\ &= \left[w\left(q_a\right)-p^{IR}q_a\right]-\left[w\left(q_f\right)-p^{RE}q_f\right]-\left[e\left(\overline{Q}\right)-e\left(\underline{Q}\right)\right].\end{aligned}$$

By Assumption 3 upon the collective rationality of frugal behaviour

$$v\left(p\left(0;N_m\right),a\right)-v\left(p\left(N;N_m\right),f\right)<e\left[Q\left(0;N_m\right)\right]-e\left[Q\left(N;N_m\right)\right]=e\left(\overline{Q}\right)-e\left(\underline{Q}\right),$$

so that, substituting $w\left(q\right)-pq$ to $v\left(p,q\right)$we have:

$$\left[w\left(q_a\right)-p\left(0;N_m\right)q_a\right]-\left[w\left(q_f\right)-p\left(N;N_m\right)q_f\right]<e\left(\overline{Q}\right)-e\left(\underline{Q}\right),$$

for any N_m. Let $N_m=N$. We have $p\left(0;N\right)=p^{IR}$ and $p\left(N;N\right)=p^{RE}$ so that we can conclude:

$$\mathscr{U}^{IR}-\mathscr{U}^{RE}<0.$$

Moreover, Assumption 4 on the social cost of militancy says that

$$b\left(m\right)-b\left(\emptyset\right)<\left[p\left(N_f;N_m\right)-p\left(N_f;N_m-1\right)\right]Q\left(N_f\right)=cQ\left(N_f\right)$$

which implies that $b\left(m\right)-b\left(\emptyset\right)<\left[p\left(N_f;N\right)-p\left(N_f;0\right)\right]Q\left(N_f\right)$. What is of more interest is that, for $N_f=0$ and $N_f=N$ it also states

$$\begin{aligned}b\left(m\right)-b\left(\emptyset\right)&<\left[p\left(0;N_m\right)-p\left(0;N_m-1\right)\right]q_aN=cNq_a,\\ b\left(m\right)-b\left(\emptyset\right)&<\left[p\left(N;N_m\right)-p\left(N;N_m-1\right)\right]q_fN=cNq_f.\end{aligned}$$

As a consequence, we also have

$$\begin{aligned}\mathscr{U}^{IR}-\mathscr{U}^{U} &= \left[w\left(q_a\right)-p^{IR}q_a+b\left(m\right)-e\left(\overline{Q}\right)\right]-\left[w\left(q_a\right)-p^{U}q_a+b\left(\emptyset\right)-e\left(\overline{Q}\right)\right]\\ &= \left[b\left(m\right)-b\left(\emptyset\right)\right]-\left(p^{IR}-p^{U}\right)q_a\\ &= \left[b\left(m\right)-b\left(\emptyset\right)\right]-cNq_a\\ &< 0,\end{aligned}$$

from Assumption 2.

Similarly, we have

$$\begin{aligned}\mathscr{U}^{RE}-\mathscr{U}^{C} &= \left[w\left(q_f\right)-p^{RE}q_f+b\left(m\right)-e\left(\underline{Q}\right)\right]-\left[w\left(q_f\right)-p^{C}q_f+b\left(\phi\right)-e\left(\underline{Q}\right)\right]\\ &= \left[b\left(m\right)-b\left(\phi\right)\right]-\left(p^{RE}-p^{C}\right)q_f\\ &= \left[b\left(m\right)-b\left(\phi\right)\right]-cNq_f\\ &< 0,\end{aligned}$$

again from Assumption 2.

We now compare $\mathscr{U}^{U}$ to both $\mathscr{U}^{RE}$ and $\mathscr{U}^{C}$.

We have

$$\begin{aligned}\mathscr{U}^{U}-\mathscr{U}^{C} &= \left[w\left(q_a\right)-p^{U}q_a+b\left(\phi\right)-e\left(\overline{Q}\right)\right]-\left[w\left(q_f\right)-p^{C}q_f+b\left(\phi\right)-e\left(\underline{Q}\right)\right]\\ &= \left[w\left(q_a\right)-p^{U}q_a\right]-\left[w\left(q_f\right)-p^{C}q_f\right]-\left[e\left(\overline{Q}\right)-e\left(\underline{Q}\right)\right].\end{aligned}$$

Assumption 3 upon the collective rationality of frugal behaviour implies that

$$e\left(\overline{Q}\right)-e\left(\underline{Q}\right)>\left[w\left(q_a\right)-p^{U}q_a\right]-\left[w\left(q_f\right)-p^{C}q_f\right],$$

so that we obtain

$$\mathscr{U}^{U}-\mathscr{U}^{C}<0.$$

Finally

$$\begin{aligned}\mathscr{U}^{U}-\mathscr{U}^{RE} &= \left[w\left(q_a\right)-p^{U}q_a+b\left(\phi\right)-e\left(\overline{Q}\right)\right]-\left[w\left(q_f\right)-p^{RE}q_f+b\left(m\right)-e\left(\underline{Q}\right)\right]\\ &= \left[w\left(q_a\right)-p^{U}q_a\right]-\left[w\left(q_f\right)-p^{RE}q_f\right]-\left[b\left(m\right)-b\left(\phi\right)\right]-\left[e\left(\overline{Q}\right)-e\left(\underline{Q}\right)\right].\end{aligned}$$

Observe that $p^{RE}=\underline{p}+\beta^{-1}\underline{Q}+cN=p^{C}+cN$. It follows that

$$\begin{aligned}\mathscr{U}^{U}-\mathscr{U}^{RE} &= \left\{cNq_f-\left[b\left(m\right)-b\left(\phi\right)\right]\right\}\\ &\quad-\left\{\left[e\left(\overline{Q}\right)-e\left(\underline{Q}\right)\right]-\left[\left(w\left(q_a\right)-p^{U}q_a\right)-w\left(q_f\right)-p^{C}q_f\right]\right\}\end{aligned}$$

where from Assumption 3 upon the collective rationality of frugal behaviour and from Assumption 4 upon the social cost of militancy,

$$\begin{aligned}e\left(\overline{Q}\right)-e\left(\underline{Q}\right)&>\left[w\left(q_a\right)-p^{U}q_a\right]-\left[w\left(q_f\right)-p^{C}q_f\right],\\ cNq_f&>b\left(m\right)-b\left(\phi\right)\end{aligned}$$

so that both terms are positive and the sign of $\mathscr{U}^{U}-\mathscr{U}^{RE}$ is indeterminate. It

depends upon the relative magnitude of the costs of militancy and the environmental costs. If the latter dominates, $\mathscr{U}^{RE} > \mathscr{U}^{U}$, the converse otherwise.

To summarize

$$\mathscr{U}^{IR} < \mathscr{U}^{RE} < \mathscr{U}^{C},$$
$$\mathscr{U}^{IR} < \mathscr{U}^{U} < \mathscr{U}^{C}.$$

4 Conclusion

The double prisoner's dilemma leads, unsurprisingly, to the worst welfare outcome. Demand policies, targeting individual behaviours, or simply individual action to reduce demand, are more effective than supply strategies to improve environmental outcomes. Supply strategies are not only ineffective but are beneficial to the industry by raising its revenues. This is definitely something most environmental militants do not intend.

This paper is a first step toward the analysis of the effects of militancy on oil markets. Further developments could include the assessment of the impact of some elasticity in oil demand on the these results and the study of distributional effects of oil price increases induced by militancy. Indeed, many lower income oil consumers already spend a higher percentage of their income on energy, despite using less of it, than higher income ones. They bear a greater cost when oil becomes more expensive and could be collateral victims of environmental militancy. On the other hand, if higher income consumers became more frugal, it would provide both financial and environmental relief to everyone - but especially for the poorest, who are often, also, the most exposed to environmental problems.

References

[1] Breton B., Sbragia L. and Zaccour G. (2010) "A Dynamic Model for International Environmental Agreements", Environmental and Resource Economics, vol. 45 (1) pp. 25–48.

[2] EIA (2018) International Data. Washington DC: Energy Information Administration.

[3] Greenpeace International (2018) Act. Amsterdam: Greenpeace International. Web page accessed on July 18, 2018. https://www.greenpeace.org/international/act/

[4] Herfindahl, O. C. (1967) "Depletion and Economic Theory", in: M. M. Gaffney (ed.), Extractive Resources and Taxation, Wisconsin University Press, Madison, WI, pp. 63–69.

[5] IEA (2017) Key world energy statistics. International Energy Agency: Paris.

[6] IEA (2018) Oil Market Report 2018. International Energy Agency: Paris.

[7] IPCC (2014) Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[8] Jørgensen S., Martín-Herrán G. and Zaccour G. (2010) "Dynamic games in the economics and management of pollution", Environmental Modeling & Assessment 15 (6), pp. 433-467.

[9] Labandeira X., Lageaga J.M. and Lopez-Otero X. (2017), "A meta-analysis on the price elasticity of energy demand", Energy Policy, 102 : 549-68.

[10] Ngendakuriyo F. and Zaccour, G. (2017) "Should civil society organizations cooperate or compete in fighting a corrupt government?", Mathematical Social Sciences, vol. 85, pp. 30-36.

[11] Petrosjan L. and Zaccour G. (2003) "Time-consistent Shapley value allocation of pollution cost reduction", Journal of economic dynamics and control, vol. 27 (3), pp. 381-398.

[12] 350.org (2018) About 350. New York: 350.org. Web page accessed on July 18, 2018. https://350.org/about/