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Innovations and industry growth under welfare maximisation and oligopoly

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Abstract

We analyse industry growth as driven by process innovations generated by salaried agents (see Krippendorff, 2019) under conditions of asymmetric information, rather than by entrepreneurs. We compare welfare-maximising public or cooperative firms with an oligopoly with profit-maximising firms.

There is technical uncertainty related to the fact that the impact of the agent's efforts on cost efficiency is stochastic. However, we also consider additional uncertainty related to the agent's work environment, in particular when it comes to the risk of being fired. This feature is inspired by the suggestion that Nokia's eventual failure as a producer of mobile phones was partly caused by a climate of fear (Vuori and Huy, 2016). However, fear might also explain the modest performance of public ownership under dictatorship.

It turns out that public ownership would generate higher industry growth than an oligopoly if all other circumstances are identical. As for an oligopoly, its highest industry growth occurs when the market is neither too concentrated nor too fragmented, in line with Schumpeter (2010/1942) and Aghion et al (1995). The performance of firms also depends on their work environment and on the extent to which they are short-termist (as reflected by the discount factor).

However, it also turns out that the size of the market sets an upper limit to the number of firms that can break even. This suggests increasing concentration is not necessarily part of a process of creative destruction. Some firms quit because a larger size of the market causes innovations to become too expensive. This upper limit is also decreasing in the number of firms if the discount factor is at least 0.5. The relationship between market size and the maximum number of firms becomes highly complex in the opposite case.

Keywords: public ownership, oligopoly, innovations, creative destruction.

1. Introduction

Our aim is to analyse the conditions for sustainable growth in well-being as generated by new ideas, with a focus on those who work in firms and other organisations. How is the activity that generates innovations affected by ownership, by the objectives of the employer, and by the market size and the degree of competition? We also consider the impact of management style and working conditions. At this stage, we limit ourselves to industry growth, and to cost-reducing innovations rather than new products. Inventing new products are necessary for economic development, but motor cars, television sets, computers, and mobile phones would have remained toys for a wealthy few without a long process of cost-reducing innovations.

Our focus on employed agents is inspired by studies suggesting that most innovations tend to be generated by persons inside the firm rather than by entrepreneurs (Krippendorf, 2019). We model an employee's willingness to engage in innovative activity as depending on the properties of her employer, the market in which her employer is active, and factors that can be seen as reflecting good or bad governance. We are partly inspired by endogenous growth theory, in particular to seminal contributions on innovations-driven growth (Romer, 1990, Aghion and Howitt, 1992) and to studies on the relationship between monopoly power and innovations (Schumpeter, 2010/1942, Aghion et al, 1995, Vives, 2008, Marshall and Parra, 2019, and Kyle, 2018). As for the impact of ownership, we extend the earlier principal-agent literature on the relationship between ownership/objectives and (static) cost efficiency in the spirit of De Fraja (1993) and many others to R&D-efforts. Our agency model is based on Beiner et al. (2011) and Raith (2003). We are also exploring the impact of a climate of fear (Kish-Gephart et al., 2009), because of suggestions it partly explains Nokia's demise as a producer of mobile phones (Vuori and Huy, 2016). We are also inspired by studies of growth under dictatorship (Miller and Smith, 2015, Willner and Miller, 2019).

We find that public ownership generates higher growth than in an oligopoly if all other circumstances are equal. This is not necessarily the case; factors such as good and bad governance may turn out as more important than ownership. Public ownership might for example be inferior under a dictatorship that generates a climate of fear. However, it also turns out that the size of market is related to the number of firms that can break even in an unexpected way. While the number of firms that can break is *independent* of the size of the market in Sutton (1991), who focus sunk costs related to a brand image, our model suggests that an increase in the size of the market can *reduce* this number. This phenomenon occurs under reasonable circumstances, such as a discount factor of at least 0.5. The relationship becomes more complex if this condition is not satisfied. It follows that concentration and mergers in innovative markets do not necessarily represent creative destruction. The firms that disappear are *not* inferior or backward. They have to quit or be taken over because a large market size makes the innovative activity too expensive.

We proceed as follows. Section 2 analyses innovations and growth with a focus on the agent's behaviour. The reward schedule is then treated as given. Section 3 deals with how this mechanism works under public ownership and oligopoly when the firm's objectives are reflected in its reward schedule. In section 4 we compare performance when and highlight the different impact of the size of the market affect under public and private ownership. Section 5 contains concluding remarks.

2. The agent

2.1. A basic model of R&D-efforts

We focus on economic growth as dependent on the innovative efforts of paid agents, for example engineers. Our agency model is inspired by Raith (2003) and Beiner et al. (2011), and reformulated in a multi-period setting. We also limit our attention to *process innovations*, i.e. on cost reducing innovations. Let the agent's R&D-effort at time t–1 be denoted by e_{t-1}. Let marginal costs be denoted by c and assume that they are constant with respect to output. Their value at time t is denoted by c_t, and their expected value as c_t^E. It is reasonable to assume that (the absolute value of) the *expected* relative change in the marginal costs depends on the efforts of the agent, and we simply define the effort at time $t-1$ as the relative change $|(c_t^E - c_{t-1})/c_{t-1}|$.[1] For example, the expected marginal costs at t can then be written $c_{t-1}(1-e_{t-1}) = c_{t-1}[1-(c_{t-1}-c_t)/c_{t-1}]$. However, the actual relative cost reduction will be $e_{t-1}+d_t$, where d is an approximately normally distributed random variable with a zero expected value and with the variance σ^2.[2] The employer can observe $e_{t-1}+d_t$, but not e_{t-1}.[3]

The wage is denoted by w, while k stands for a positive parameter reflecting the strength of the disutility of effort. The agent's risk-aversion is assumed to be a constant r. We ignore intrinsic motivation, so the engineer's utility at time t is expressed by the following function, which is increasing in w and decreasing in e:

$$U_t = 1 - \exp[-r(w_t - \frac{ke_t^2}{2})] \quad (1)$$

It follows that the optimal effort is zero unless the wage becomes positively dependent on effort. We therefore assume that firms adopt a linear performance-related pay schedule. Let w_{0t} and b_t be positive constants. The employer relates the wage to the observed reduction in

[1] Raith (2003) define efforts in terms of the extent to which costs are being kept lower than a given base level, but it makes more sense to treat efforts as scale invariant when dealing with economic growth.
[2] A normal distribution would imply an infinite range of d. However, 99.7% of the outcomes would fall within the interval, $[-3\sigma, 3\sigma]$, so the normal distribution is a convenient simplification for a bell-shaped distribution where d belongs to a finite interval $[-\hat{d}, \hat{d}]$, and where $\sigma^2 \approx (\hat{d}/3)^2$.
[3] We might think of these variations as the kind of noise that causes efforts to be unobservable, which is the usual explanation for the need for incentive wages instead of monitoring in the first place. However, we might also think of political interventions with potentially distortionary effects on input prices.

marginal costs, which depends on a random component and on the effort during the previous period:

$$w_t = w_{0t} + b_t(e_{t-1} + d_t). \tag{2}$$

Inserting (2) into (1) implies that the exponent of the utility function becomes linear in d_t:

$$U_t = 1 - \exp[-r(\, w_{0t} + b_t(e_{t-1} + d_t) - \tfrac{ke_t^2}{2})]\,, \tag{3}$$

The expected utility is then

$$EU_t = 1 - \exp[-r(\, w_{0t} + b_t e_{t-1} - \tfrac{ke_t^2}{2} - \tfrac{r\sigma^2 b_t^2}{2})]\,, \tag{4}$$

which means that we may as well assume that the agent maximises

$$V_t = w_{0t} + b_t e_{t-1} - \tfrac{ke_t^2}{2} - \tfrac{r\sigma^2 b_t^2}{2}. \tag{5}$$

Suppose that the agent has an infinite time horizon and that her discount factor is ρ. Consider the discounted present value (*DPV*) of the engineer's expected utility, starting from period 0:

$$E(DPV) = \textstyle\sum_{t=0}^{\infty} (\rho q)^t V_t. \tag{6}$$

The agent's reservation utility is assumed to be zero, so the participation constraint requires the employer to ensure that each $V_t \geq 0$ for each *t*. A principal who is free to choose the optimal incentive parameter would then maximise her objective function (for example profits or social welfare) with respect to the incentive parameters b_t (setting a value of w_{0t} such that $V_t = 0$). In other words, the employer has to accept that the agent maximises (7) with respect to the effort levels of each period, because it is essential that she does not wrongly blame bad results on a state of nature that only she can observe. Consider maximisation with respect to e_t. This requires solving the equation

$$\tfrac{d}{de_t}[V_t + \rho V_{t+1}] = 0, \tag{7}$$

because e_t appears only in V_t and V_{t+1}. We get:

$$-ke_t + b_t\rho = 0 \Rightarrow e(b_t) = \tfrac{b_t\rho}{k}. \tag{8}$$

It follows that the effort remains constant (given *k* and ρ) unless the wage schedule changes over time.

The agent's wage can be expressed as follows:

$$w_t = \frac{k + r\sigma^2 k^2/\rho^2}{2} e_t^2 = \frac{r\sigma^2 + \rho^2/k}{2} b_t^2. \tag{9}$$

We introduce the abbreviation

$$\phi = k + r\sigma^2 k^2/\rho^2, \tag{10}$$

so that the wage can be written:

$$w_t = \frac{\phi e_t^2}{2}. \tag{11}$$

Note that the easier procedure of maximising the firm's objective function directly with respect to $e_t = \rho b_t/k$ yields the same result as maximising with respect to the incentive parameter b_t.

In what follows, ϕ will play a crucial role. It is increasing in k, which can also be seen as reflecting the conditions under which the agent is working. The parameter ϕ is also decreasing in the discount factor, and increasing in the variance of the random shocks that determine the success of the innovative activity, and in the agent's degree of absolute risk aversion. It follows from the equality $w_t = \phi e_t^2/2$ that an increase in ϕ means that a higher wage is required for a given effort level, and vice versa. However, it will be shown below that ϕ has a negative effect on the effort, and the lower effort will reduce the wage.

2.2. Arbitrary punishments

In this section we introduce a variable that reflects the properties of the agent's work environment, including the regime under which her organisation is active. This may relate to governance quality (including rule of law, government effectiveness, regulatory quality, and control of corruption; see Kaufmann et al., 2004). For example, when it comes to the political regime, the absence of rule of law is likely to make a regime unpredictable, thus creating a climate of fear. Such factors may also be firm-specific, like in the case of the 'climate of fear' that some experts blame for Nokia's failure to maintain its leading position on the mobile phone market (Vuori and Huy, 2016, Siilasmaa, 2018). In this section follows, we shall assume that 'bad governance' means that the typical employee expects some random interference to reduce utility to zero with the probability $1-q$. This probability is assumed to be completely independent of d.

Consider the discounted present value (DPV) of the agent's expected utility, starting from period 0. It becomes V_0 if she is punished after the initial period. The probability of being punished after period 1 is $q(1-q)$, in which case the DPV becomes $V_0+\rho V_1$. The corresponding probability of being punished after period 2 is $q^2(1-q)$, in which case the *DPV* becomes $V_0+\rho V_1+\rho^2 V_2$. By extension, the expected value of the *DPV* is therefore:

$$E(DPV) = (1-q)[V_0 + q(V_0 + \rho V_1) +$$

$$+q^2(V_0 + \rho V_1 + \rho^2 V_2) + q^3(V_0 + \rho V_1 + \rho^2 V_2 + \rho^3 V_3)+\ldots] = \sum_{t=0}^{\infty}(\rho q)^t V_t. \quad (12)$$

Maximising with respect to e_t requires solving the equation

$$\frac{d}{de_t}[V_t + q\rho V_{t+1}] = 0, \quad (13)$$

because e_t appears only in V_t and V_{t+1}. We get:

$$-ke_t + b_t\rho q = 0 \Rightarrow e(b_t) = \frac{b_t\rho q}{k}. \quad (14)$$

It follows that low job security given the wage schedule leads to lower efforts, also when there is no change in coefficient for the disutility of effort. The agent's wage becomes

$$w_t = \frac{k + r\sigma^2 k^2/(\rho q)^2}{2} e_t^2 = \frac{r\sigma^2 + (\rho q)^2/k}{2} b_t^2 = \frac{\phi e_t^2}{2} \quad (15)$$

when the parameter ϕ is now

$$\phi = k + r\sigma^2 k^2/(\rho q)^2. \quad (16)$$

Note that ϕ is then decreasing in q, and hence increasing in the probability $1-q$ of an arbitrary punishment that terminates her appointment and yields zero utility. We may still maximise the firm's objective function directly with respect to $e_t = \rho q b_t/k$ instead of b_t.

3. Innovations in different types of firms

3.1. Public ownership

We make the simplifying assumption that the public firm is a welfare-maximising monopoly. It would be technically more complicated to focus on a mixed oligopoly, which would either require the public firm to have a more complex objective function, or firms to face increasing marginal costs (which is in addition unrealistic; see Martin, 2014). Private firms can survive also by being more efficient, but we focus on endogenous costs, so we abstain from making a priori assumptions on comparative cost efficiency. Moreover, empirical studies have provided mixed results (Mühlenkamp, 2015, Perelman, and Pestieau, 2020).

Let x_i stand for consumption of commodity *i*, let p_i stand for its price, and let α_i stand for a weight parameter. We assume that all individuals have identical utility functions of the following form:

$$u = \sum_{i=1}^{k} x_i \ln \alpha_i. \tag{17}$$

We may think of the value of the industry output as small in relation to the national income *Y*. It is well known that the Cobb-Douglas family of utility functions predict that each individual spends the proportion α_i of her incomes (in the absence of savings) on commodity *i*. Let *A* stand for $\alpha_i Y$; we skip the subscript *i* in what follows, because we confine ourselves to a partial equilibrium. We assume that the economy is so large that *Y* remains approximately constant when conditions change in this particular industry. The market demand function is then:

$$x = \frac{A}{p}. \tag{18}$$

This approach is convenient for a comparison between welfare maximisation and an oligopoly. It has on the other hand a weakness. The optimal effort level is not defined for if the market size is large and the discount factor is low.

The following assumption ensures that there exists a meaningful solution (i.e a solution where $e < 1$):

Assumption 1. $A < \phi/2$.

The public firm's marginal costs at time *t* are related to efforts and marginal costs at *t*–1 as follows:

$$c_t = c_{t-1} - \frac{c_t - c_{t-1}}{c_{t-1}} c_{t-1} = c_{t-1}(1 - e_{t-1}) = c_{t-1}\left(1 - \frac{\rho q b_{t-1}}{k}\right). \tag{19}$$

This means that $b_{(t-1)}$ enters the expression for the marginal costs via $e_{(t-1)}$. The engineer's wage (which is a fixed cost) depends on b_t (or e_t).

The firm decides on output given its marginal costs, which are based on decisions at an earlier period, by maximising the utility of a typical consumer subject to a break-even constraint.[4] In other words, it produces as much as possible given the marginal costs at period *t* and given the agent's wage as expressed by (11):

[4] The break-even constraint also means that there is no need to analyse the welfare impact of a positive or negative surplus.

$$x_t = \frac{A - \phi e_t^2/2}{c_{t-1}(1-e_{t-1})}. \tag{20}$$

The utility derived from consuming x_t is $\alpha \ln x_t/N$, where N stands for the number of individuals. However, the term $-\alpha \ln N$ is a constant, so we focus on $\alpha \ln x_t$. Denote the initial marginal costs by c_0, and the firm's discount factor by δ. Suppose that it maximises the discounted present value of the consumer benefits. As explained in the appendix, we get:

$$e^G = \frac{1-\delta}{2-3\delta} \pm \sqrt{\left(\frac{1-\delta}{2-3\delta}\right)^2 - \frac{2\delta A}{(2-3\delta)\phi}}. \tag{21}$$

Note that the plus-sign applies for $\delta > 2/3$, and the minus-sign for the opposite case. The solutions are identical if $\delta = 2/3$. There is no discontinuity; Figure 1 in section 4 illustrates the relationship between growth and the discount factor. Note that Assumption 1 ensures that $e^G < 1$ holds true and that the solution is real also when $\delta < 2/3$.

It follows from (20) that the output is:

$$x_t^G = \frac{A - \phi\left(e^G\right)^2/2}{c_0\left(1-e^G\right)^{t-1}}. \tag{22}$$

The growth rate under public ownership, $(x_t - x_{t-1})/x_{t-1}$ is therefore:

$$g^G = \frac{e^G}{1-e^G} = \frac{\sqrt{\left(\frac{1-\delta}{3\delta-2}\right)^2 + \frac{2\delta A}{(3\delta-2)\phi}} - \frac{1-\delta}{3\delta-2}}{\frac{2\delta-1}{3\delta-2} - \sqrt{\left(\frac{1-\delta}{3\delta-2}\right)^2 + \frac{2\delta A}{(3\delta-2)\phi}}} = \frac{\sqrt{(1-\delta)^2 + 2\delta A(3\delta-2)} - 1 + \delta}{2\delta - 1 - \sqrt{(1-\delta)^2 + 2\delta A(3\delta-2)}}. \tag{23}$$

3.2. Innovations in an oligopoly

Most leading industries in Western economies tend to be oligopolistic, so we focus on *n*-firm oligopoly, assuming Cournot behaviour. Note, however, that the demand function from the previous section is associated with another drawback under profit maximisation. The profit-maximising solution is not defined if *n*=1. Profits would then be decreasing in output or increasing in price, so the monopolist would have an incentive to reduce output and increase the price in any given allocation. We have to assume that the authorities will not permit such a situation to emerge; the case of a private but regulated monopoly has to be analysed elsewhere.

Marginal costs in firm *i* at time *t* are related to efforts and marginal costs at *t*–1 as follows:

$$c_{ti} \equiv c_{(t-1)i} - \frac{c_{ti} - c_{(t-1)i}}{c_{(t-1)i}} c_{(t-1)i} = c_{(t-1)i}\left(1 - e_{(t-1)i}\right) = c_{(t-1)i}\left(1 - \frac{\rho q b_{(t-1)i}}{k}\right). \tag{24}$$

Like in the previous section, marginal costs depend on $b_{(t-1)i}$ via $e_{(t-1)i}$.

The employer has decided on the incentive parameter and the wage intercept before deciding on output. We first maximise the *DPV* of the profits of firm *i* with respect to all x_{ti} ,with the discount factor δ, given the expected marginal costs (and hence $e_{(t-1)i}$) and the wage:

$$\pi_{DPV} = \sum_{t=1}^{\infty} \delta^{t-1} \left[\frac{A}{x_t} x_{ti} - c_{ti} x_{ti} - w_{ti}\right]. \tag{25}$$

The first-order condition for each firm *i* and each period *t* is:

$$\frac{A}{x_t} - \frac{A}{x_t^2} x_{ti} - c_{ti} = 0. \tag{26}$$

Add all the *n* first-order conditions for period *t*, divide by *n*, and solve for $x_t = \sum_{i=1}^{n} x_{ti}$. This yields the following market output as a function of the (unweighted) average $\bar{c}_t$ of the marginal costs:

$$x(\bar{c}_t) = \frac{(n-1)A}{n\bar{c}_t}. \tag{27}$$

Insert (27) into the first-order condition and rearrange to get the market share of firm *i*:

$$\frac{x_{ti}}{x(\bar{c}_t)} = \frac{n\bar{c}_t - (n-1)c_{ti}}{n\bar{c}_t}. \tag{28}$$

Firm *i*:s profits at period *t* are therefore:

$$\pi_{ti} = \frac{A[n\bar{c}_t - (n-1)c_{ti}]^2}{(n\bar{c}_t)^2} - \frac{\phi}{2} e_{ti}^2. \tag{29}$$

Suppose that each firm *i* chooses the values of b_{ti} and w_{t0} that maximise $\sum_{t=1}^{\infty} \delta^{t-1} \pi_{ti}$, i.e. the *DPV* of their stream of profits. As explained in the appendix, we get:

$$-\phi e_1 + \frac{2A(n-1)^2}{n^3(1-e_1)} \frac{\delta}{1-\delta} = 0. \tag{30}$$

When maximising with respect to e_{2i}, we can take the initial marginal costs $c_0(1-e_1)$ as given. A similar procedure yields an equation that is otherwise similar to (30), but with e_1 replaced by e_2. The same logic applies to all other periods. It follows that the employer will always choose the same value *b* of b_{ti}, which means that the effort is the same for all *t.* Solve for e_t=*e* and index the solution by *C*:

$$e^C = 0.5 - \sqrt{0.25 - \frac{2\delta A(n-1)^2}{(1-\delta)\phi n^3}}. \tag{31}$$

It follows from (27) that the time path of total output becomes $x_t = (n-1)A/[nc_0(1-e^C)^t]$. This means that the expected growth rate is $g^C = (x_t - x_{t-1})/x_{t-1}$ at each stage, and independent of c_0:

$$g^C = \frac{e^C}{1-e^C} = \frac{0.5-\sqrt{0.25-2\delta A(n-1)^2/[(1-\delta)\phi n^3]}}{0.5+\sqrt{0.25-2\delta A(n-1)^2/[(1-\delta)\phi n^3]}}. \tag{32}$$

Note that (21) and (22) might give the impression that a real solution might be non-existent if *A*, which can be interpreted as the size of the market, is too large. Corollary 2 below describes the circumstances under which this problem matters and suggests that the problem occurs only when capitalists are short-termist.

When it comes to the impact of market structure, it follows from a companion paper that the model also has a Schumpeterian flavour: the highest rate of innovations-based growth is neither associated with monopoly nor (near-perfect) competition, but with an oligopoly in which n=3 (see Willner and Miller, 2019).[5] This follows from the fact that the highest value of $(n-1)^2/n^3$ occurs when $n = 3$.

4. A comparison of public ownership and oligopoly

4.1. Innovative activity

It will be useful to formulate the following Lemma 1 below on how the parameter values in the model affect growth under both private and public ownership:

Lemma 1: The efforts and the growth rates are increasing in the discount factor and in the size of the market, and decreasing in the parameter that reflects disutility of effort, risk, risk-aversion, and bad governance.

Proof: See appendix.

As for the intuition, a high discount factor increases the weight given to future payoffs, so the incentive to pay for potential innovations becomes higher, whereas short-termism would have the opposite effect. The positive impact of a larger market size as reflected in *A* is explained by the fact that becomes easier to pay for cost-reducing innovations under both types of ownership. As for ϕ, an increase makes the wage higher for a given effort level. For example, the presence of a non-zero probability of a random punishment (i.e. if $q < 1$), would mean a higher ϕ, and hence a lower effort. It follows that increased job security (i.e, a greater probability

[5] See for example Carlin and Soskice (2006, p.549) on empirical support for an inversely U-shaped relationship between innovation and competition.

that the employment is not terminated) will increase efforts. A Nokia-style of a climate of fear would on the other hand have the opposite effect, as also reflected in the impact of the parameter for the disutility of effort: an unpleasant work environment would be likely to mean a higher value of ϕ via *k,* or via both *k* and *q* in the extended model of the agent's decisions in section 2.2.

It will also be useful to establish the impact of the parameter ϕ on the equilibrium wage. It turns out that the fact that wage becomes higher for a *given* effort does not mean that the equilibrium wage is increasing in ϕ:

Corollary 1. The agent's equilibrium wage is decreasing in ϕ both under public ownership and in the oligopoly.

Proof: See appendix.

Note that the wage is $\phi e^2/2$. Corollary 1 shows that the positive impact of ϕ for a *given e* is overshadowed by the negative impact of ϕ on the effort. It follows that the equilibrium wage and the growth rate are affected in the same way by the factors that affect ϕ (i.e, by $1-q$, k, σ^2, *r,* and by $1-q$ in the extended version). For example, the model associates poor working conditions and low job security with both a low wage and a low growth rate. The same applies to high risk and high risk aversion.

Next, consider the growth rates under both forms of ownership.

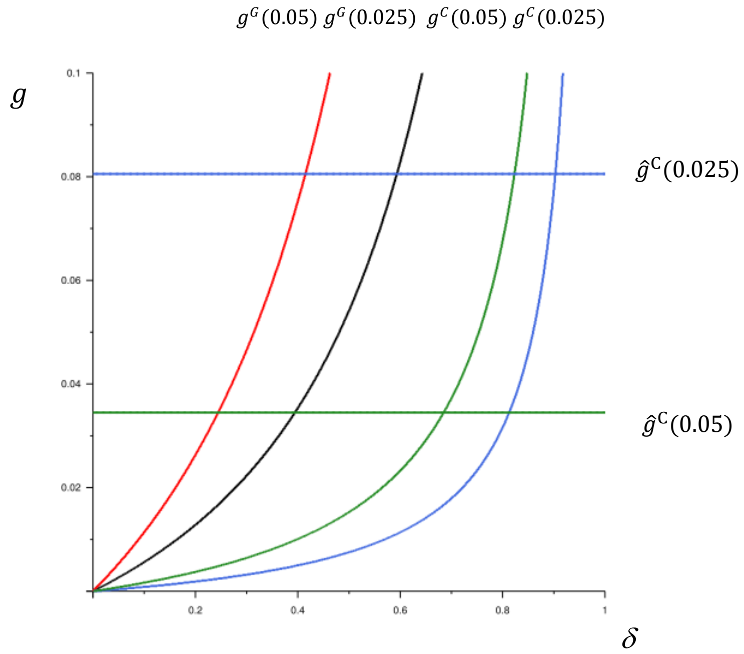
Proposition 1. Industry growth is higher ceteris paribus in a welfare maximising public monopoly than in the oligopoly.

Proof: See appendix.

Figure 1 below may help to clarify the intuition:

$g^G(0.05)$ $g^G(0.025)$ $g^C(0.05)$ $g^C(0.025)$

Figure 1. Growth under public ownership and in an oligopoly



The figure displays growth rates under public ownership (g^G) and in a three-firm oligopoly (g^C) when A/ϕ is 0.05 and 0.025 respectively. The horizontal lines represent the maximum growth rates under oligopoly for these values of A/ϕ, given that higher values would prevent firms from breaking even. As can be expected, a higher value of A/ϕ means higher growth. However, it also means that it becomes more difficult to break even.

Note that 1 proposition associates public ownership with higher industry growth only if the market size (as reflected in A) and the parameter ϕ are the same. The intuition for the potential superiority is based on the fact that wider objectives and the monopoly position strengthen the incentive and ability to pay for cost-reducing innovations.

4.2. Non-creative destruction: Changes in the number of firms that can break even

Welfare maximisation and oligopoly differ not only when it comes to growth performance and the price-cost margin. It is obvious from (21) that the size of the market does restrict the equilibrium under public ownership if the discount factor is higher than 2/3. However, we shall demonstrate that the market size creates an upper limit for an oligopoly. Moreover, this upper limit is decreasing under reasonable circumstances. Note that this upper limit exists despite the fact that we have simplified the analysis by setting the agent's reservation utility equal to zero.

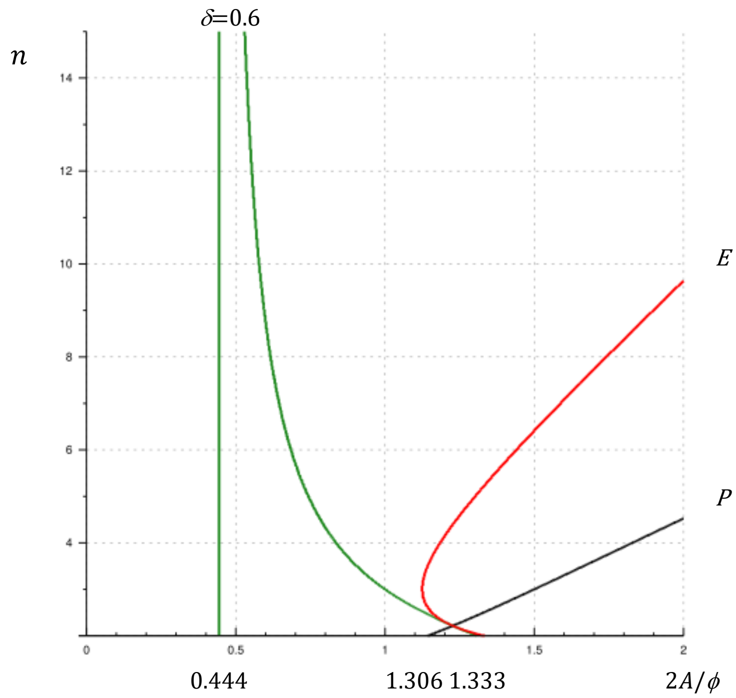
Like in Sutton (1991), the market size is assumed to be reflected in the numerator of a unitary elastic demand function, here *A*. However, it turns out that it is convenient to focus on $2A/\phi$, which is proportional to the size of the market. We can then formulate the following proposition:

Proposition 2. The feasible market structures can be characterised in the following way for a Cournot-oligopoly where innovations are generated by salaried agents and where $1 > \delta \geq 0.5$*: The upper limit* $\hat{n}$ *is infinite when* $2A/\phi \leq [(1-\delta)/\delta]^2$ *and finite and decreasing in* $2A/\phi$ *if* $[(1-\delta)/\delta]^2 < 2A/\phi \leq [4(1-\delta)/(2-\delta)]^2$*. No firm can break even if* $2A/\phi > [4(1-\delta)/(2-\delta)]^2$ *except for when n* = 2 *and* $2A/\phi \leq 2(1-\delta)/\delta$*.*

Proof: See appendix.

To clarify the intuition behind the proposition, we plot the number of firms that can break even as a function of $2A/\phi$ for a value of δ in the relevant region (more precisely, for $\delta = 0.6$). Note that the vertical axis starts from *n* = 2. To the left of each curve is its vertical asymptote, which is the limit when *n* the number of firms approaches infinity. Firms are profitable to the left of the curve, and there is no upper limit for the number of firms that can break even to the left of the asymptote $2A/\phi = 0.444$, but it is obvious that the relationship between $\hat{n}$ and the market size is negative to the right of this point, because of the curve's negative slope. To the right of the point $2A/\phi = 1.306$ (where the curve intersects the line *n*=2), all values of $2A/\phi$ are so high that firms cannot break even, with the exception of a small interval on the horizontal axis, i.e. $1.306 < 2A/\phi \leq 1.333$. Points below the black line (*P*) are also profitable, but only if they also lie below the lower part of the red curve (*E*), because points to its left are such that no equilibrium exists. (This exceptional area is hardly visible in the figure.) It follows that the regions of a nonexistent, decreasing, or a constant upper limit (equal to 2) represent 33.33 per cent, and 64.63 per cent, and 2.04 per cent of the interval in which firms can break even.

Figure 2. Market size and the maximum number of firms when $\delta = 0.6$



However, with even higher discount rates, such as 0.9, the curve *P* would be inside of *E*, so there are no exceptions to the rule that firms can break even only on and to the left of the green curve. The area in which the maximum number of firms is decreasing then represents 90.66 per cent of the region in which firms can break even. This suggests that the phenomenon of an upper limit that is decreasing in the market size is not just a special case of no quantitative significance.

Table 1 below highlights how firms can be 'destroyed' by a larger market:

Table 1. Market size, market structure, and industry growth when δ = 0.6

$2A/\phi$	$\hat{n}$	g^C
0 < $2A/\phi < 0.444$	No upper limit	0< $g^C \leq$ 0.125
0.445	2134	3.167×10^{-4}
0.450	214	3.144×10^{-3}
0.460	77	8.886×10^{-3}
0.480	34	0.021
0.500	22	0.033
0.600	8	0.105
0.800	4	0.274
1.000	3	0.500
1.300	2	0.727
1.320	2	0.818

We normally think of creative destruction as a process where old-fashioned firms unable to compete with new and innovative firms and therefore being destroyed (Schumpeter, 2010/1942). However, the process in this model means that an autonomous increase in $2A/\phi$ can force firms to exit despite the fact that all firms are equally efficient ex post. Note however that the simplicity of the model means that the actual numbers in the model should not be taken too seriously.

The relationships become much more complicated when firms are short-termist, as illustrated by Table 2 below. For example, there exists a range of values of $2A/\phi$ such that firms can break even only if their number is high or low, but not in intermediate cases.

Table 2. Market size, market structure, and industry growth when δ = 0.345

$2A/\phi$	N	g^C
0 < $2A/\phi \leq 3.204$	No upper limit	0< $g^C \leq 0.968$
3.3	2	0.469
3.3	3	No equilibrium
3.3	$n \geq 4$	0< $g^C \leq 0.743$
3.5	n=2	0.637
3.5	n=3-4	No equilibrium
3.5	n=5	Negative profits
3.5	$n \geq 6$	0< $g^C \leq 0.269$
3.61	n=2	0.637
3.61	n=3-4	No equilibrium
3.61	n=5-9	Negative profits
3.61	n=10-122	$1.724\times10^{-3} < g^C \leq 0.235$
3.61	$n \geq 123$	Negative profits
$3.623 < 2A/\phi < 3.708$	n=2	0.647 < $g^C < 734$
$3.623 < 2A/\phi < 3.708$	n=3-4	No equilibrium
$3.623 < 2A/\phi < 3.708$	$n \geq 5$	Negative profits
$3.708 \leq 2A/\phi \leq 3.797$	$n \geq 2$	0.734 < $g^C < 0.967$
$3.708 \leq 2A/\phi \leq 3.797$	n=3-5	No equilibrium
$3.708 \leq 2A/\phi \leq 3.797$	$n \geq 6$	Negative profits
$2A/\phi > 3.797$		Negative profits or no equilibrium

However, $2A/\phi$ can also be given a different interpretation. Suppose that we keep the market size constant. An increase in $2A/\phi$ would then reflect a decrease in the parameter ϕ. It follows that such a decrease will have no impact for low values of $2A/\phi$, but it may also either increase or decrease the number of firms that can break even. If $2A/\phi$ becomes high enough, no firm would be able to break even. It is also possible that we end up in a region where there is both an upper and a lower limit to the number of firms that can break even. The intuition behind the potentially restricted scope for market fragmentation (or for the existence of a market at all) when ϕ is low can be understood in the light of Corollary 1: the agent's equilibrium wage is decreasing in ϕ, so low risk aversion and good working conditions can make innovations too expensive.

5. Concluding remarks

Our analysis suggest that public ownership represents a potential to generate higher industry growth than under oligopoly. It also follows that a growing market can limit the number of firms that can break even; the maximum number of firms is decreasing in market size under reasonable circumstances. This means that bankruptcies and mergers are not necessarily signs of creative destruction in the sense of Schumpeter (2010/1942).

However, the literature provides mixed evidence on the comparative performance of public and private ownership (Mühlenkamp, 2015, Perelman and Pestieau, 2020). Our analysis suggests that factors related to the quality of governance are also important. A climate of fear has been provided as an explanation for failures within the private business community (Kish-Gephart et al, 2009, Vuori and Huy, 2016), but may also explain lacklustre growth performance under dictatorship.

We are also aware of the fact that those who are responsible for innovations are not necessarily behaving like Pavlovian dogs; we plan to extend the analysis to potential intrinsic motivation (see, for example, Besley and Ghatak, 2018, and Bitzer et al., 2007, Willner and Grönblom, 2020).

Appendix

The public firm: The relevant part of the public firm's objective function $\Omega = \Omega(e_1, e_2, \dots)$ can be written:

$$\Omega = \alpha \ln \frac{A - \phi e_1^2/2}{c_0} + \delta\alpha \ln \frac{A - \phi e_2^2/2}{c_0(1 - e_1)} + \delta^2 \alpha \ln \frac{A - \phi e_3^2/2}{c_0(1 - e_1)(1 - e_2)} + $$
$$+ \delta^3 \alpha \ln \frac{A - \phi e_4^2/2}{c_0(1-e_1)(1-e_2)(1-e_3)} + \cdots \quad \text{(A.1)}$$

Consider the effort in period 1 and rewrite (A.1) as follows:

$$\Omega = \alpha \ln(A - \phi e_1^2/2) - \frac{\delta\alpha \ln(1 - e_1)}{1 - \delta} - \frac{\alpha \ln c_0}{1 - \delta} + \delta\alpha \ln(A - \phi e_2^2/2) + $$
$$\delta^2 \alpha \ln \frac{A - \phi e_3^2/2}{(1-e_2)} + \delta^3 \alpha \ln \frac{A - \phi e_4^2/2}{(1-e_2)(1-e_3)} + \cdots \quad \text{(A.2)}$$

All terms in (A.2) except for the two first consist of constants when differentiating with respect to e_1. The first-order condition when differentiating with respect to e_1 is:

$$\alpha \left[\frac{-\phi e_1}{A - \phi e_1^2/2} + \frac{\delta}{(1-\delta)(1-e_1)} \right] = 0. \quad \text{(A.3)}$$

Solve for e_1, and note that it is obvious that we get the same expression for all other periods as well. This yields (21).

The private firm: Use the facts that c_{ti} = $(1 - e_{(t-1)i})c_{(t-1)i}$ and c_{tj} = $(1 - e_{(t-1)j})c_{(t-1)j}$ for writing the profits at *t* as follows:

$$\pi_{ti} = A \left[\frac{\sum_{j \neq i} c_{(t-1)j}(1 - e_{(t-1)j}) - (n-2) c_{(t-1)i}(1 - e_{(t-1)i})}{c_{(t-1)i}(1 - e_{(t-1)i}) + \sum_{j \neq i} c_{(t-1)j}(1 - e_{(t-1)j})} \right]^2 - \frac{\phi}{2}(e_{ti})^2. \quad \text{(A.4)}$$

Assume that the initial marginal cost is given and equal to c_0 in all firms. The discounted present value can then be written:

$$\sum_{t=1}^{\infty}\delta^{t-1}\pi_{ti} = \frac{A}{n^2} - \frac{\phi(e_{1i})^2}{2} + \delta\left\{A\left[\frac{\sum_{j\neq i}c_0(1-e_{1j})-(n-2)c_0(1-e_{1i})}{c_0(1-e_{1i})+\sum_{j\neq i}c_0(1-e_{1j})}\right]^2 - \frac{\phi(e_{2i})^2}{2}\right\} +$$

$$+\delta^2\left\{A\left[\frac{\sum_{j\neq i}c_0(1-e_{1j})(1-e_{2j})-(n-2)c_0(1-e_{1i})(1-e_{2i})}{c_0(1-e_{1i})(1-e_{2i})+\sum_{j\neq i}c_0(1-e_{1j})(1-e_{2j})}\right]^2 - \frac{\phi(e_{3i})^2}{2}\right\} +$$

$$+\delta^3\left\{A\left[\frac{\sum_{j\neq i}c_0(1-e_{1j})(1-e_{2j})(1-e_{3j})-(n-2)c_0(1-e_{1i})(1-e_{2i})(1-e_{3i})}{c_0(1-e_{1i})(1-e_{2i})(1-e_{3i})+\sum_{j\neq i}c_0(1-e_{1j})(1-e_{2j})(1-e_{3j})}\right]^2 - \frac{\phi(e_{4i})^2}{2}\right\} + \cdots. \quad \text{(A.5)}$$

Strictly speaking, each firm chooses the optimal value of b_{ti}, but we make the shortcut of maximising directly with respect to the efforts relating to each period, because efforts are proportional to b_{ti}. Maximise first with respect to e_{1i}. Set the derivative of (A.5) equal to zero, impose ex post symmetry across firms, and rearrange. This yields (30).

Proof of Lemma 1. The impact of A, and ϕ is obvious from (31) and (21) and the fact that growth is monotone, continuous and increasing in effort. As for the impact of δ on g^G, consider first the case of $\delta < 2/3$. It is sufficient to prove that the effort is monotone and increasing in δ. Suppose as an antithesis that the derivative of (21) is negative. Routine calculations would then imply that this would require $A > \phi/2$, contrary to Assumption 1. Similar calculations apply to the case of $\delta > 2/3$. The result for g^C follows directly from differentiating (32). Lemma 1 is thereby proved.

Proof of Corollary 1. Note that the equilibrium wage is $w = \phi e^2/2$ and differentiate with respect to ϕ:

$$\frac{dw}{d\phi} = \frac{e^2}{2} + \phi e\frac{\partial e}{\partial \phi}. \quad \text{(A.6)}$$

First, consider public ownership assuming that $\delta < 2/3$, and apply (21):

$$\frac{dw^G}{d\phi} = \frac{e^G}{2}\left[\frac{1-\delta}{2-3\delta} - \sqrt{\left(\frac{1-\delta}{2-3\delta}\right)^2 - \frac{2\delta A}{(2-3\delta)\phi}} - \frac{\frac{2\delta A}{(2-3\delta)\phi}}{\sqrt{\left(\frac{1-\delta}{2-3\delta}\right)^2 - \frac{2\delta A}{(2-3\delta)\phi}}}\right] = \frac{-\frac{1-\delta}{2-3\delta}\left(e^G\right)^2}{2\sqrt{\left(\frac{1-\delta}{2-3\delta}\right)^2 - \frac{2\delta A}{(2-3\delta)\phi}}}. \quad \text{(A.7)}$$

If $\delta < 2/3$, we get:

$$\frac{dw^G}{d\phi} = \frac{e^G}{2}\left[\frac{1-\delta}{3\delta-2} + \sqrt{\left(\frac{1-\delta}{3\delta-2}\right)^2 + \frac{2\delta A}{3\delta-2\phi}} + \frac{\frac{2\delta A}{(3\delta-2)\phi}}{\sqrt{\left(\frac{1-\delta}{3\delta-2}\right)^2 + \frac{2\delta A}{(3\delta-2)\phi}}}\right] = \frac{-\frac{1-\delta}{3\delta-2}\left(e^G\right)^2}{2\sqrt{\left(\frac{1-\delta}{3\delta-2}\right)^2 + \frac{2\delta A}{(3\delta-2)\phi}}}. \quad \text{(A.8)}$$

Next, consider the oligopoly. Profits per period in each firm are $(A/n^2)-\hat{V}-\phi e^2/2$. Use (31) and differentiate the wage with respect to ϕ and rearrange:

$$\frac{dw^G}{d\phi}=0.5\left(0.5-\sqrt{0.25-\frac{2\delta A(n-1)^2}{(1-\delta)\phi n^3}}-\frac{2\delta A(n-1)^2}{(1-\delta)\phi n^3}\right)$$

$$-\phi\left(0.5-\sqrt{0.25-\frac{2\delta A(n-1)^2}{(1-\delta)\phi n^3}}\right)\frac{\frac{2\delta A(n-1)^2}{(1-\delta)\phi^2 n^3}}{2\sqrt{0.25-\frac{2\delta A(n-1)^2}{(1-\delta)\phi n^3}}}=$$

$$=0.25\left(-0.5+\sqrt{0.25-\frac{2\delta A(n-1)^2}{(1-\delta)\phi n^3}}+\frac{2\delta A(n-1)^2}{(1-\delta)\phi n^3}\right)=-\frac{e^2}{4}<0. \qquad (A.9)$$

It follows that w is decreasing in ϕ, so higher values of r, k, σ^2 and $(1-q)$ mean a lower wage, and vice versa. Corollary 1 is thereby proved.

Proof of Proposition 1. By Lemma 1, efforts are increasing in δ under both forms of ownership. This also implies that the inverse functions are such that the discount factor is increasing in effort. The fact that growth is monotone and increasing in effort means that we can focus on effort, and in particular on the inverse relationship between the discount factor and the effort level. In the case of public ownership, solve (A.3) for δ:

$$\delta=\frac{2(e-e^2)}{2A/\phi+2e-3e^2}. \qquad (A.10)$$

As for the case of private ownership, solve (30) for δ:

$$\delta=\frac{e-e^2}{2A(n-1)^2/(\phi n^3)+e-e^2}. \qquad (A.11)$$

Suppose as an antithesis that $g^C>g^G$ and hence $e^C>e^G$. This would mean that a given growth rate g is associated with a higher discount factor in the case of public ownership than in the oligopoly. Combining (10) and (11) would then imply:

$$e^2>\frac{2A(n^3-2n^2+4n-2)}{\phi n^3}. \qquad (A.12)$$

However, firms cannot break even unless $A/n^2\geq\phi e^2/2$. Higher efficiency in an oligopoly where firms can break even would therefore require

$$\frac{1}{n^2}>\frac{n^3-2n^2+4n-2}{n^3}, \qquad (A.13)$$

or

$$0 > (n^2 - n + 2)(n - 1). \tag{A.14}$$

The parenthesis to the left has no real roots and is always positive, and the parenthesis to the right is positive because $n \geq 2$. It follows that (A.14) cannot be satisfied, so efforts are lower in private firms than under public ownership if the firms break even. It follows that industry growth is higher under public ownership. Proposition 1 is thereby proved.

Proof of Proposition 2: Note that nonnegative profits mean:

$$\pi_i = \frac{A}{n^2} - \frac{\phi}{2}e^2 \geq 0 \Leftrightarrow \frac{2A}{\phi n^2} - e^2 \geq 0. \tag{A.15}$$

As follows from (31), this means that profits are nonnegative for values of $2A/\phi$ under the following condition:

$$\sqrt{0.25 - \frac{2\delta A(n-1)^2}{(1-\delta)\phi n^3}} \geq 0.5 - \frac{2A}{\phi n^2}\left[1 + \frac{\delta(n-1)^2}{n(1-\delta)}\right]. \tag{A.16}$$

This can happen when the expression to the right is negative, i.e. when:

$$\frac{2A}{\phi} \geq \frac{(1-\delta)n^3}{2[(1-\delta)n+\delta(n-1)^2]}, \tag{A.17}$$

In the opposite case, profits are non-negative when:

$$\frac{2A}{\phi} \leq \left[\frac{(1-\delta)n^2}{(1-\delta)n+\delta(n-1)^2}\right]^2. \tag{A.18}$$

The upper boundary of (A.18) is monotone and decreasing in *n* if *n* ≥ 2 and $\delta \geq$ 0.5. It approaches a finite value when *n* approaches infinity:

$$\lim_{n\to\infty} \frac{2A}{\phi} = \left(\frac{1-\delta}{\delta}\right)^2. \tag{A.19}$$

Setting *n* = 2 in the boundary of (A.18) yields the following expression, which is higher than (A.19) when $\delta \geq 0.5$:

$$\frac{2A}{\phi}\Big|_{n=2} = \left[\frac{4(1-\delta)}{2-\delta}\right]^2. \tag{A.20}$$

However, it is obvious from (31) that there exist no meaningful solution unless

$$\frac{2A}{\phi} \leq \frac{(1-\delta)n^3}{4\delta(n-1)^2}, \tag{A.21}$$

Tedious but straightforward calculations then verify that Proposition 2 holds true (but more details are available upon request).

References

ACEMOGLU, D., and J. A. ROBINSON (2012). *Why Nations Fail: the Origins of Power, Prosperity, and Poverty*. London: Profile Books.

AGHION, P., N. BLOOM, R. BLUNDELL, R. GRIFFITH, & P. HOWITT (2005), 'Competition and Innovation: An Inverted U-relationship', *Quarterly Journal of Economics,* 120(2), 543-69.

AGHION, P. & P. HOWITT (1992), 'A model of Growth through Creative Destruction', *Econometrica* , 60 (March), 49-37.

BITZER, J., W. SCHRETTL & P. J. H. SCHRÖDER (2007).' Intrinsic Motivation in Open Source Software Development', *Journal of Comparative Economics,* 35, 160-169.

CARLIN, W. & D. SOSKICE (2006), *Macroeconomics. Imperfections, Institutions & Policies,* Oxford and New York; Oxford University Press.

KAUFMANN, D., A. KRAAY & M. MASTRUZZI (2004), 'Governance Matters III: Governance Indicators for 1996, 1998, 2000, and 2002', *World Bank Economic Review* **18**(2), 253–87.

KISH-GEPHART, J. J., J. DETERT, L. K. TREVIÑO, & A.C. EDMONDSON (2009), 'Silenced by Fear: The Nature, Sources, and Consequences of Fear at Work', *Research in Organizational Behavior* 29, 163-193.

KRIPPENDORFF, K. (2019), *Driving Innovation from Within. A Guide for Internal Entrepreneurs,* New York: Columbia University Press.

KYLE, M. K. (2018), 'Are Important Innovations Rewarded? Evidence from Pharmaceutical Market', *Review of Industrial Organization* 53, 211-234.

MARSHALL, G. & A. PARRA (2019), 'Innovation and Competition: The Role of the Product Market', *International Journal of Industrial Organization* 65, 221-247.

MARTIN, S. (2014), 'Globalization and the natural limits of competition' Chapter 1, pp. 4-56 in Neumann, M. & J. Weigand (Eds.), *The International Handbook of Competition,* Cheltenham: Edward Elgar.

MÜHLENKAMP, H. (2015). 'From state to market revisited: A reassessment of the empirical evidence on the efficiency of public (and privately owned) enterprises', *Annals of Public and Cooperative Economics, 86*(4), 535–557.

PERELMAN, S. & P. PESTIEAU (2020), 'The Performance of Public Enterprises', Ch. 30, pp. 533-552 in Bernier, L., M. Florio, & P. Bance (Eds.), *The Routledge Handbook of State-Owned Enterprises,* London and New York: Routledge.

RAITH, M. (2003), 'Competition, Risk and Managerial Incentives', *American Economic Review*, 93, 1425-1436.

ROMER, P.M. (1990), 'Endogenous Technological Change', *Journal of Political Economy* 98(5), Part 2, S71-S102.

RYAN, R.M. & E.L. DECI (2000), 'Intrinsic Motivation: Classic Definitions and New Directions', *Contemporary Educational Psychology,* 25: 54-67.

SCHUMPETER, J. (2010/1942), *Capitalism, Socialism and Democracy,* London and New York: Routledge.

SIILASMAA, R. (2018), *Transforming NOKIA: The Power of Paranoid Optimism to Lead Through Colossal Change,* New York: McGraw-Hill Education.

SUTTON, J. (1991), *Sunk Costs and Market Structure. Price Competition, Advertising and the Evolution of Concentration,* Cambridge, Mass. and London, UK: MIT Press.

VIVES, X. (2008), 'Innovation and Competitive Pressure', *Journal of Industrial Economics* 56(3), 419-464.

VUORI, T.O. & Q.N. HUY (2016), 'Distributed Attention and Shared Emotions in the Innovation Process: How Nokia Lost the Smartphone Battle', *Administrative Science Quarterly,* 69(1), 9-52.

WILLNER, J. & M. MILLER (2019), 'Schumpeterian Growth or Socialism: Where Governance Matters', presented at the Royal Economic Society Conference, April, the University of Warwick.

WILLNER, J. & S. GRÖNBLOM (2020), 'Motivation and Performance in State-Owned Enterprises', in Florio, M. & L. Bernier (Eds.), *Routledge Handbook on State-owned Enterprises*.