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Market dynamics in on-rail competition

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Abstract

On-rail competition is perhaps the most far-reaching form of deregulation of the railways, giving travellers several options on a single line. It aims to lower fairs and raise quality of service, thereby boosting demand and social welfare. Concerns have been raised, however, regarding if effective competition is possible on such a market, allowing two or more operators to be profitable and eliminating through incentives or regulation the purchase by one operator of the others' access rights, thus restoring monopoly. In addition, the effect of competition on total welfare is unclear. The issue of how to regulate the market and conduct capacity allocation in order to maximise welfare is also as yet unanswered.
Addressing these issues, the present paper studies a duopoly market through simulations. It builds on the hypothesis that competition occurs between trains with close departure times. Results indicate that total welfare increases significantly when going from profit-maximising monopoly to competition, as consumers make large gains while operators' profits fall. The way the regulator allocates departure slots has significant importance for market outcomes, including prices, frequencies and total welfare. In particular, it is possible to improve welfare by regulating the succession of departures. If trading in access rights is allowed, a would-be monopolist has incentives to buy its competitors' slots for a price they would accept. A monopolist that uses high frequency of departures as a deterrence strategy against competition increases frequency a lot compared to the profit-maximising level.

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Keywords: on-rail competition; simulation model; deregulation; Stackelberg game

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1. Introduction

On-the-track competition is a new phenomenon on the railway market, where operators compete on the same line for passengers. Similar reforms on the bus market have in some situations unleashed fierce, unsustainable competition and eventual return to monopoly; concerns have thus been raised over how prices, frequencies, travel-volumes and overall social welfare will develop. In particular, the existence of stable equilibrium with more than one player is questioned.

The regulator plays a crucial role in this respect. Because of capacity constraints, it is by necessity involved in decisions regarding departure times and frequencies of service. Tweaks to regulatory proceedings alter the optimal strategies of market participants, and in turn social welfare and other outcomes. Assuming that the regulator strives to achieve a stable market equilibrium and high social welfare through the means of on-rail competition, what policies should be adopted?

We suggest a simulation model with realistic parameters where operators compete on frequency and price. The model is built to facilitate comparison between different regulatory settings, including a duopoly market where the regulator allocates departure times; a profit-maximising monopoly; a large number of competitors; and others. It also includes bench-mark scenarios, such as welfare maximisation with a no subsidies constraint.

The model allows for individual prices to be set for each departure, and it takes account of each departure's relative position in time. In this way it builds explicitly on the hypothesis that competition occurs not only between operators but between departures that are close in time. This makes it possible to study how prices vary over the day, depending on the relative intensity of competition at certain times. Possible operator strategies to lessen the pressure of price competition are explored.

The results indicate that total welfare is higher under competition compared to profit-maximising monopoly. Also, a competitive situation with two service providers is sustainable under certain assumptions. There are good prospects for a new entrant to reach profitability in a market dominated by a former monopolist. The combined profit of two competing firms is substantially lower than the monopoly profit however, possibly implying incentives to merge operations into a single unit, or for one operator to buy the other's departure slots. This would go against the intentions of the reform of course.

2. Background

Deregulation of the railways is an international trend. It began in 1989 in Sweden with the separation of operations from infrastructure management. The UK has come far in this respect, with public tenders for all lines. In one way or another, the deregulation trend has spread throughout Europe and beyond.

A few countries are now taking this one step further, through introducing competition not just for the tracks but on the tracks. Since 2001 the Swedish freight market is completely deregulated, and since 2010, all profitable passenger lines in the country are also open for competition (Alexandersson & Hultén, 2009). (Unprofitable lines are for the most part allocated through a public tendering process.) Other countries that are experimenting with on-rail competition include Austria, the Czech Republic, Italy and the UK (Beria, Redondi, & Malighetti, 2014). The result has in most cases been a monopoly situation, sometimes complemented by smaller niche actors.

This opens up new possibilities, but also raises many questions. Supposedly, competition should lead to better services and lower prices for passengers. Competition is widely believed to have positive welfare effects compared to profit-maximising monopoly. This is in spite of the fact that the dynamics of such a market is as yet poorly understood.

More is known about deregulation of other modes. When the British bus market was deregulated in the 1980s, a new entrant emerged to compete with the incumbent on only a small share of submarkets. Where they did, this led to a short period of fierce competition on price as well as frequency. Profitability for both competitors rapidly sank well into the negative and within a year or so one of them closed shop. At that point ticket prices increased again and departure frequencies decreased; although prices remained lower and frequencies higher compared to before deregulation. This may indicate that operators behaved so as to dissuade others from taking up competition. (Evans, 1990)

Railways are different from buses however. For one thing, schedules are by necessity decided on in cooperation with the infrastructure provider. Because of this, under certain assumptions a market with on-the-track competition may actually behave more like certain markets outside of the transportation field.

3. The model

The simulation model describes a duopoly, and it is constructed as a combination of sub-games for each of the decision variables; frequency and price. In the upper-level frequency game, each operator decides how many departures to offer in order to maximise profit. The game continues until both players are satisfied; this may be either at a Nash[2] or a Stackelberg equilibrium point, as is more thoroughly discussed below. It is played at discrete points in time.

The lower-level price game is played continuously. There is a separate price game for each combination of number of departures that the two competitors may choose. Prices are set individually for each departure so as to maximise profit over all the operator's departures. The solution to the price game is the Nash equilibrium; profits at this point are the decision variables in the frequency game.

Operators only decide on the number of departures, and then the regulator decides on the order of departures and on departure times. The headway is identical between any two successive departures.

Through this design, the model captures a key characteristic that distinguishes the railway market from that of e.g. buses; that the regulator is by necessity involved in scheduling, and has the means to do so in ways that may or may not be in the operator's best interest.

With this model design, we ignore problems such as operators trying to arrive at stations just before their competitors to grab market share (anyway less common in book-ahead markets, as railways tend to be).

3.1. Demand and consumer surplus

The preferred departure times[3] (PDTs) of potential passengers have a distribution $\varphi(t)$ over the day such that $\int \varphi(t)dt$ equals the daily potential demand. We assume that every potential passenger has a PDT t. Trains depart at times $T_1, T_2, \ldots, T_N$, where N is the number of daily departures, equal to the sum of the two operators' departures: $N = N_{Incumbent} + N_{Challenger}$. The corresponding ticket prices for those departures are $p_1, p_2, \ldots, p_N$. Passengers are identical in the sense that the generalised cost for any passenger with PDT t is

$$c(t) = \min_n(\alpha|t - T_n| + p_n) \tag{1}$$

The number of passengers with PDT t that choose to travel are

$$D(t) = \varphi(t) - \beta c(t) \tag{2}$$

where $\beta > 0$ and $D(t) \geq 0$.

Now introduce τ_n as the PDT, relative to T_n, where departures T_n and T_{n+1} have equal generalised cost, thus enabling us to define the "catchment area" of departure T_n as $[T_{n-1}, T_n]$.

$$\tau_n = \begin{cases} \dfrac{1}{2N} + \dfrac{p_{n+1} - p_n}{2\alpha}, n \in [1, N-1] \\ \dfrac{1}{2N}, n \in [0, N] \end{cases} \tag{3}$$

The number of passengers that travel on departure *n* is

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[2] In the context of quantity the Nash equilibrium is often referred to as the Cournot or Cournot-Nash equilibrium.

[3] This may be substituted with preferred arrival time with analogous results, as we do not model variations in travel time.

$$D(n) = \int_{\tau_n - \frac{1}{N}}^{\tau_{n+1}} D(t)dt \quad (4)$$

Using equation (2) and noting that passengers' valuation of a trip falls linearly from $\mathrm{D(t)} = 0$ for any t, it can be seen that the consumer surplus is

$$CS = \int \frac{D(t)\left(\frac{\varphi(t)}{\beta} - \frac{\varphi(t) + D(t)}{\beta}\right)}{2} dt = \int \frac{D^2(t)}{2\beta} dt \quad (5)$$

This integral must be evaluated separately for each departure. The consumer surplus can now be written as

$$CS = \frac{1}{2\beta} \int \varphi^2(t)dt + \frac{\beta}{2} \sum_n \int_{\tau_{n-1} - \frac{1}{N}}^{\tau_n} (\alpha t + p_n)^2 dt - \int \varphi(t)c(t)dt \quad (7)$$

(See appendix B for calculations.)

3.2. Operators' profits

The profit for each operator is defined as the sum of profits for all its departures on a day:

$$\Pi = \sum_{n \in V} (p_n D_n(\mathbf{p}) - K) \quad (8)$$

where V is the set of departures run by that operator and p_n is the profit contribution per passenger[4] for departure n and cost per departure T_n.

Each operator chooses its prices so as to maximise Π, conditional on the other operator's prices.

3.3. Solving the model

There is a separate price game for every point in frequency space (i.e. every combination of number of daily departures for the two operators). Operators have the means to set prices individually for each departure. They adjust prices to maximise profit under a static assumption about their competitor: A Nash equilibrium is when neither operator wants to change its prices, conditional on the other operator's prices. We assume that the parameters are such that there is either a unique Nash equilibrium or two symmetric equilibria, where the incumbent has the same frequency in one as the challenger does in the other and vice versa. The outcome of all possible such equilibria are known to the regulator when allocating departures.

It is assumed that operators have the means to take into consideration the ownership of adjacent departures when setting fares. This may or may not be true, depending on the capabilities of their price-generating software. The argument for this assumption is that if it has a significant effect on operators' strategies and profits, then there are incentives to develop such capability. (If it has no effect, then no harm is done anyway.)

In the frequency game, the outcomes of all possible price games are known to both operators. In equilibrium, neither operator regrets its choice of frequency, conditional on that the other operator chooses its frequency to maximise profit as well. We have studied both a static strategy, similar to the price game, and a dynamic one, where operators foresee their competitor's reaction to their choice of frequency. The case for each of these possible assumptions is further explored below, as are their implications. For now we simply note that while the former results in a Nash equilibrium, the latter may result in a different, Stackelberg, equilibrium.

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[4] If the marginal cost is zero then p_n is equivalent to the average ticket price.

3.4. Parameters

The simulation model is run and more closely examined for a certain set of parameter values, which we refer to as our base case. Then a sensitivity analysis is made to test results over a wider range of parameters – see Appendix A. In our base case we use $\alpha = 900$, $\beta = -10$, $D_{pot.} = 15000$ and $K = 40000$[5]. This corresponds to a fast end-to-end market over 450 km with ca 5,000 daily trips, 10 daily departures per direction and fares at ca 500 in the competitive scenario; numbers that are similar to the Swedish Stockholm-Göteborg line, with prices in Swedish kronor.

4. Results

Through running the simulation model with the parameters of our base case we have been able to find a number of interesting results. Numbers shown also reflect those parameter values, although the described results are tested to hold true over a range of values. In the first section, we look at a common situation prior to deregulation: monopoly.

4.1. Going from monopoly to competition

A special case of certain interest is the profit-maximising monopoly. It can take many forms; from virtual integration of infrastructure and operations into a single enterprise, to time-limited concessions won through a public tender, and government-owned monopoly operators with the instruction to maximise profit. The underlying logic for setting fares and frequencies is the same in all these cases however, and they can thus be described by a single model. Monopoly is here treated in the model by setting the number of departures of the challenger equal to zero and optimising the profit of the incumbent by varying its offered frequency.

Under monopoly, the incumbent chooses to run six departures per day, to maximise daily profit at 5,100,000. Fares are the same for all departures, and they are high compared to in other types of market dynamics (see Figure 1). Frequencies and ridership are low in such comparison. A large profit is made from the operations, although depending on the underlying scheme, these may to a large extent be returned to the public through a tendering process. Social welfare is substantially smaller than its theoretical maximum. Looking only at the consumer surplus, the gap between the actual figure under monopoly and optimality is greater still.

A useful benchmark at this point is a monopolist that strives to optimise total welfare under a no subsidies constraint. Frequencies in such scenario are around 50% higher compared to the profit maximising monopoly. Prices are dramatically lower in the benchmark case, profit contribution per passenger around 90% lower than in monopoly, in the base case.

These figures do not reflect dynamics such as incentives for quality improvements and cost reduction provided by profit maximisation, as that is beyond the scope of the model. They do highlight the shortcomings of profit maximising monopoly however, thus suggesting why policy makers may wish to replace monopoly operations with free competition.

When bus markets open for competition, incumbents have been seen to raise frequencies and/or lower prices as deterrence strategies against competition (Evans, 1990). Such behaviour is less likely on the railway market. Prices need not be lowered in advance because they can very quickly be adjusted when needed, thanks to the prevalence of yield management methods. Frequencies may also be unlikely to be adjusted in anticipation of competition since, as is shown below, the monopoly frequency may be well below the frequency of the market-leader under competition, indicating that a very large increase would be needed to dissuade potential challengers to enter the market.

[5] The cost per departure is calculated as $K = \gamma_1 * \text{travel time} + \gamma_2 * \text{travel distance}$ where parameters γ_1 and γ_2 are taken from (ASEK6)

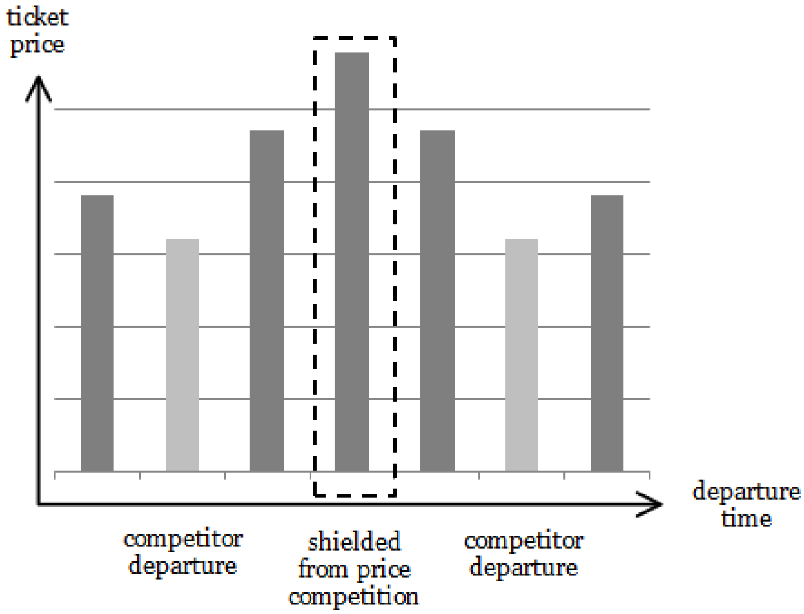

Figure 1. Different fares on different departures.

Under on-rail competition, operators compete for passengers on frequency and price. As stated above, the attractiveness of each departure is determined by the generalised cost to passengers that travel with it, in this study modelled as a combination of scheduling cost and ticket price. While frequency and thus scheduling cost is fixed in the short term, prices vary with changes in demand.

Lower prices increase the demand for a departure in two ways: through luring passengers over from adjacent departures and by creating new demand. (New demand in this sense includes travellers that switch from other modes or routes.) As luring passengers from adjacent departures is of no benefit to the operator unless that departure is run by a competitor, the price-level depends not only on the frequency of departures but also on how different operators' departures are mixed.

Given the frequency and mix of departures, operators set the prices for each departure so as to maximise profit. They do so in competition until equilibrium is reached. We assume that the equilibrium will be of the Nash type.

With Nash prices as a given, operators choose frequencies so as to maximise profit. Results from the frequency game are spelled out more extensively below. Here, it is interesting to note the results of a certain benchmark: the socially optimal frequency under Nash prices. In our base case this is the point 5:5 in frequency space. The more general result is that operators will offer equal or close to equal frequency of service. The intuition for this result is that equally many departures gives passengers the most option to choose from, regardless of their PDT. This increases competition and pushes prices downwards. Unfortunately, this is not the point picked by operators.

4.2. Asymmetry of frequencies

Operators' incentives and constraints are strictly symmetrical in the model; their cost structures are identical, there are no economies of scale, demand is allocated in the same way, and the regulator treats them according to the same set of principles. Given this symmetry, one might expect them to offer equal frequency of service in equilibrium. But to the contrary, one operator tends to have a substantially larger number of departures than the other. The frequency equilibrium is thus asymmetric, i.e. the operators' frequencies are different from one another in equilibrium.

Table 1. Comparison of points in frequency space

	6:0 (monopoly)	Welfare maximising	6:2	9:2 (Nash)	4:2	4:1 (Stackelberg)	Many competitors
Combined profit	5,100,000	0	2,200,000	2,200,000	2,200,000	3,500,000	320,000
Average fare	730	28	200	200	190	340	64
Daily ridership	7,300	14,000	13,000	13,000	13,000	11,000	14,000
Consumer surplus	2,700,000	10,500,000	8,000,000	8,000,000	8,000,000	6,100,000	15,700,000
Total welfare	7,800,000	10,500,000	10,200,000	10,200,000	10,200,000	9,600,000	16,000,000

The asymmetric frequency equilibrium is a consequence of operators having an incentive to lower their exposure to price competition. When operators have equally many departures, the regulator spreads those departures so that for any PDT that a passenger has, the two nearest departures belong to different operators. This makes price competition ever-present.

If instead one operator is able to increase its market presence beyond 50%, a pseudo-monopoly situation appears at certain times of the day. At such times, all the nearest departures belong to the same operator, making them somewhat shielded from price competition. In effect, every "extra" departure that the market leader adds will have this feature, creating an incentive for the already dominant operator to increase its frequency further.

A challenger operator, by contrast, lacks such incentives. It is likely to have a market share below 50%, why any extra departure added will face full price competition and hence be less profitable. This creates a rationale to keep the number of departures low. All the challenger's departures face full price competition, why its average prices are lower than the incumbent's. Passengers take notice, pushing up average ridership on the challenger's departures.

As price competition is fiercest when the two operators have equally many departures, profits are dragged down at such points in frequency-space, creating incentives for both operators to avoid them. Because of this asymmetric frequency equilibrium, the likely equilibrium point is one where the incumbent offers a frequency similar to what it did under monopoly while the challenger offers a smaller frequency (assuming base case parameters and a Nash equilibrium in the frequency game), together raising the combined frequency as experienced by travellers, compared to under monopoly.[6]

By diverting from the diagonal, firms raise profits somewhat but reduce total welfare. This might imply that the freedom of train-operators to decide freely on the number of departures is inefficient. Given that they do have this possibility, however, they will choose the frequencies that maximise their respective profits. And since each operator is affected by the other's decision, they will change their decisions until equilibrium is reached.

The phenomenon described here appears even though, as mentioned above, the cost of operations is linear in terms of number of departures in the model. In reality, economies of scale seem to benefit the operator with the most departures on a line (Wheat & Smith, 2015), which may enhance the frequency asymmetry even further.

4.3. The regulator's options

The regulator may seek to raise social welfare beyond the results described above. Assuming that competition is the chosen means and that explicit price regulation is not an option, the regulator may try to look for options to either force or incentivise operators to choose different frequencies.

The incumbent seems to run too many departures compared to optimality. The regulator has the option of course to decline a request for capacity on the track, in order to reduce the frequency of the incumbent compared to the Nash equilibrium. However, this is in effect similar to forcing the incumbent to pursue a Stackelberg strategy (described in more detail below). According to the logic of asymmetric frequency equilibria, the challenger is then

[6] There is an equivalent equilibrium where the challenger offers more departures and the incumbent fewer. In the following this case is not described explicitly as it is analogous to the scenario deemed more likely but with reversed roles.

given incentives to also decrease frequency, contrary to the regulator's intentions. Fares, ridership and consumer surplus are changed in the same direction as under an actual Stackelberg strategy, all in the opposite direction of the regulator's wishes. Profits may increase under such a scheme, but not enough to keep social welfare from falling.

In order to reach the social-optimality point of the frequency game, the regulator must have the means not only to decrease but to increase frequencies compared to the market equilibrium. One might envision rules that force operators to have a certain minimum frequency. The dynamics of the price game is unaffected by this. However, the regulating agency may not know what frequency is optimal, as it lacks information about the value of individual departures such as ridership and fares. In addition, forcing operators to run more departures than they had planned for may result in a service of poor quality, or not be feasible at all because of the long lead-times and large financial obligations associated with acquiring rolling stock and scaling up operations.

Another option is to skew incentives in order to make the diagonal seem more attractive to operators. The regulator might even abstain from trying to maximise competition, in cases where the competitors offer close to equal frequencies. Instead, it bundles the challenger's departures closer together, thus easing the price pressure there. The priority should be to lessen the burden on the challenger while preserving the pressure on the incumbent as much as possible, in order to force a new Nash equilibrium with lower combined profits compared to the previous equilibrium point.

The problem with this idea is that while the incumbent seems to gain from a reordering of departures to lessen price competition, the challenger does not. The intuition for this is that without drastic changes, departures belonging to the challenger will continue to lie close to the competitor's departures. For the incumbent, in contrast, its existing shielded pseudo-monopoly areas can easily be expanded. Simulations confirm that any changes large enough to have a positive impact on the behaviour of the challenger will increase average ticket prices enough to make the welfare effect of the regime negative.

Yet another idea is to vary access charges according to the number of departures that an operator runs. It seems however that this will not work without dramatic variations which are probably unfeasible due to practicality and fairness reasons.

4.4. The Nash equilibrium

What is the likely behaviour of operators when competition is introduced? One possibility is this: When a challenger enters the market, the dynamics switch from that of a monopoly to a duopoly market. Both operators try to maximise their profit in the frequency-game, as depicted in Figure 2. The challenger acts under the assumption that the incumbent will run six departures for the foreseeable future, as it did under monopoly. Given this assumption, the challenger maximises its profit by offering two departures.

This is a new point in frequency space – 6:2. Average ticket prices fall as a consequence of competition, and daily ridership increases thanks to lower prices and more departures to choose from. The combination of lower prices and greater demand result in an almost three-fold increase in consumer surplus. The two firms' combined profit is less than half what the previous monopolist earned. Social welfare is substantially higher than under monopoly.

The incumbent will react to the new circumstances too, however, by increasing its number of departures from six to nine. This point – 9:2 – is a Nash-equilibrium; neither the incumbent nor the challenger regrets its choice of frequency, under the assumption that its competitor's choice is fixed. In the Nash equilibrium, the number of departures almost doubles compared to the monopoly situation. Passengers don't gain much from the switch from 6:2 to 9:2 however, largely because the rescheduling they need to do is increased only slightly (by six minutes on average in the base case).

			Number of departures Incumbent						
			4	5	6	7	8	9	10
No. of dep. Chal.	0	profit Incumbent	5 050 000	5 090 000	5 110 000	5 110 000	5 100 000	5 080 000	5 680 000
		profit Challenger	0	0	0	0	0	0	0
	1	profit Incumbent	2 610 000	2 770 000	2 800 000	2 770 000	2 810 000	1 340 000	1 350 000
		profit Challenger	880 000	730 000	550 000	440 000	400 000	180 000	180 000
	2	profit Incumbent	1 350 000	1 450 000	1 530 000	1 560 000	1 590 000	1 600 000	1 510 000
		profit Challenger	850 000	760 000	700 000	650 000	610 000	530 000	380 000
	3	profit Incumbent	860 000	890 000	880 000	920 000	930 000	940 000	1 000 000
		profit Challenger	690 000	620 000	580 000	540 000	500 000	490 000	450 000
	4	profit Incumbent	650 000	590 000	600 000	590 000	570 000	580 000	580 000
		profit Challenger	650 000	500 000	450 000	420 000	400 000	470 000	350 000

Figure 2. Frequency game matrix

Prices are affected by two contradicting forces. The incumbent introduces new departures that are shielded from price competition due to the forces behind the asymmetric frequency equilibrium as described in section 4.2. The challenger, meanwhile, is under pressure to retain market share so it must lower fares instead. The average net effect for passengers of these contradicting trends is close to zero. Unchanged fares and a negligible effect on scheduling cost results in unchanged demand. Consequentially, consumer surplus is also roughly unchanged. Combined profit is slightly lower than at 6:2, as the incumbent's profit increases slightly while the challenger's profit falls by 24%. Social welfare is close to, but below, the level in 6:2, i.e. still substantially higher than under profit-maximising monopoly [7].

Remember that the regulator orders departures to maximise competition. This implies that all the challenger's departures have competitors as the nearest departures both before and after. This is not necessarily true for the incumbent, as it has more departures. This makes the challenger more exposed to price competition, why it will offer lower prices than the incumbent on average. Similar differences in incumbent and challenger prices might appear due to a long-standing good reputation among customers by the former, as suggested by Fröidh & Byström (2013) and Ruiz-Rúa & Palacín (2013). While price differences may be reinforced by such phenomena, our result appears even as any such effects of pre-existing differences between the operators are excluded.

When calculating social welfare in the traditional way, society thus gains from a switch from regulated profit-maximising monopoly to competition. A remark that can be made, however, is that the combined profits of the two firms may be larger than the difference between social welfare in competition and under profit-maximising monopoly. What this implies is that if the former monopoly was government-owned but the two competing firms are privately owned, than the combined welfare of travellers and the government may decrease when introducing competition, even as total welfare increases. If profits are transferred abroad, then national social welfare may decrease when competition is introduced.

Compared to the socially optimal frequency under Nash prices, combined profit is slightly higher in the Nash equilibrium. Consumer surplus, by contrast, is smaller in Nash equilibrium, and the difference is large enough to offset the effect of higher profits and reduce total welfare compared to the socially optimal frequency.

[7] Profits make up a large share of total welfare under profit-maximising monopoly. If revenues go to the government and it uses these to replace policies that are distortionary to the economy, such as taxes, then the effect on total welfare over the entire economy may be much smaller. In the base case, the welfare increase almost vanishes when recalculating monopoly profits (but not post-deregulation profits) using commonly used values for marginal costs of public funds.

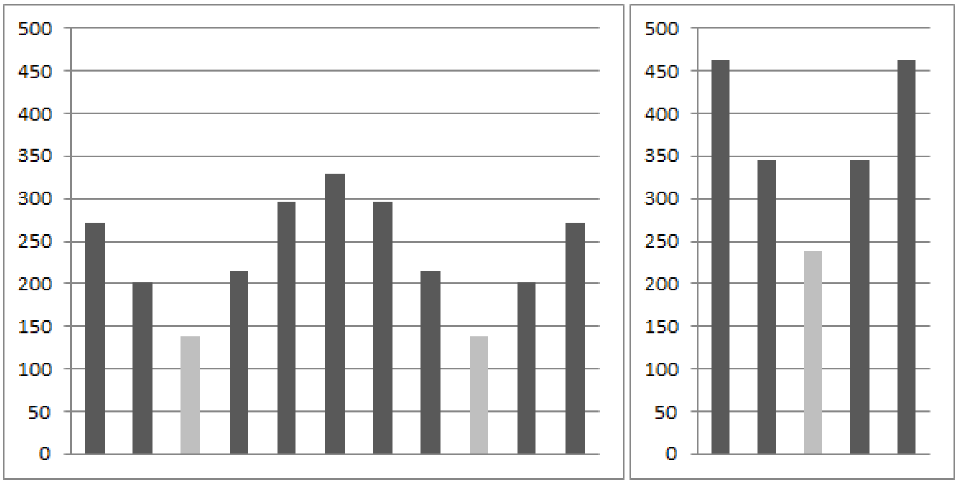

Figure 3. Prices per departure at 9:2 (Nash equilibrium; left) and 4:1 (Stackelberg equilibrium; right) respectively. Incumbent departures are coloured dark grey and challenger departures light grey.

There is a symmetrical Nash equilibrium where the challenger chooses nine departures and the incumbent chooses two. All results described above remain the same at this point, but with reversed roles. Apart from this, it is not obvious that they will behave according to this strategy at all.

4.5. The Stackelberg equilibrium

Operators may behave according to the logic of a Stackelberg game. Preconditions for this is that one operator – the incumbent, say – understands that its competitor will react dynamically to its own choice of frequency, that it foresees how the forces behind asymmetry of frequencies (see section 4.2) affect its competitor, and that it acts strategically to take advantage of these insights.

If it follows this strategy, the incumbent will choose four departures instead of nine in our base case. The immediate effect of this move is an intensifying exposure to price-competition that eats into the profit of the incumbent. The challenger's profit rises sharply, however, as it attracts more customers for each departure.

More interestingly, an opportunity opens up for the challenger to raise its profit even further, by changing its decision on frequency from two departures to one. The challenger benefits from being able to charge slightly higher prices while reducing cost. The bigger winner is the incumbent however, as it gains market share despite sharp price increases; its profit is up 63% compared to the Nash equilibrium. This new point – where the incumbent runs four departures and the challenger one – is the Stackelberg equilibrium, with the incumbent as the Stackelberg leader.

The incumbent is assumed to be a more natural Stackelberg leader as it has an existing capacity in terms of rolling stock and support functions that can be both costly and time consuming to create as well as do dismantle.

In the Stackelberg equilibrium, there are not necessarily more departures than under monopoly. Combined profit has fallen by around a third, ridership is up 50%, ticket prices are half the previous level, consumer surplus is more than doubled and social welfare is around a quarter higher compared to under monopoly. Compared to the Nash equilibrium, social welfare is somewhat lower, with profits rising more than 50% while consumer surplus is markedly lower.

It may seem peculiar that the Stackelberg leader lowers supply compared to the Nash scenario. This is in line, however, with the asymmetry of frequencies as described in section 4.2. When the incumbent offers fewer departures, they move toward symmetry in frequency space, thus increasing competition and hurting profit. The challenger's best response is to move away from symmetry, i.e. to decrease its own frequency as well.

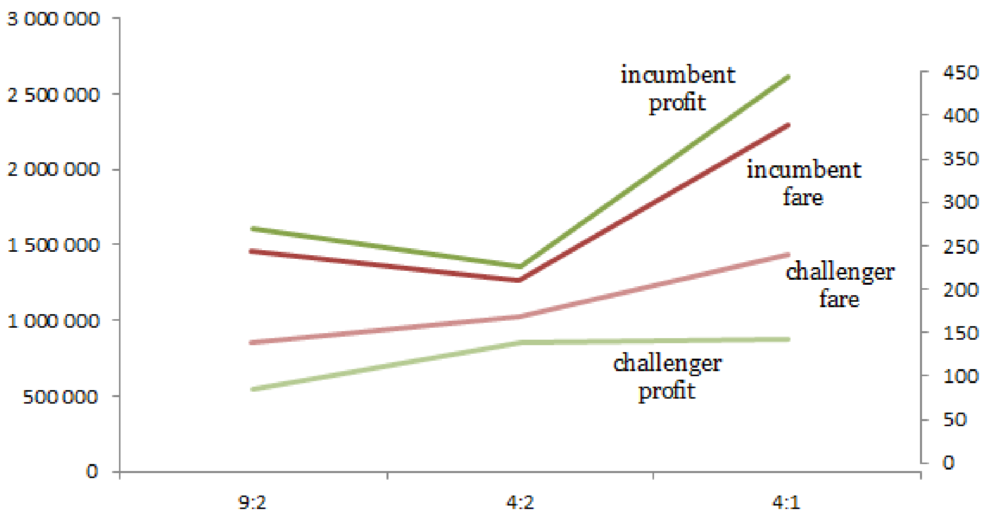

Figure 4. Comparing profits (left-hand scale) and average fares (right-hand scale) at different points of equilibrium.

4.6. Other options

In a duopoly market, competition is less than perfect and operators' profits do not decrease towards zero, as discussed above. Policy makers may therefore wish to tax those earnings. One option to their disposal is to raise infrastructure charges. We have looked at the effects of a flat fee per departure that is high enough to lower total profits by around a third.

The problem with this is that it amounts to a substantial increase in the cost per departure, thus altering the incentives of the frequency game. Therefore, the equilibrium switches to a point with fewer departures and higher fares, resulting in a welfare loss that is well above what the government earns from the charge increase. (This inefficiency of infrastructure charge increases that go beyond what is motivated by scarcity and wear and tear is unsurprising. In fact, it holds generally that it is optimal to operate an economy at the production-possibilities frontier, implying that intermediary goods – including infrastructure – shall not be taxed. Diamond and Mirrlees (1971) show that this result holds without loss of generality even in presence of distortionary taxation, i.e. in a realistic setting.)

Hitherto, we have assumed that the market will take the form of a duopoly. It may do. Anecdotal evidence indicate that ca two to three operators compete when a line opens for on-the-track competition, including in Italy (Beria, Redondi, & Malighetti, 2014) and the Czech Republic (Zdenek, Kvizda, Jandová, & Rederer, 2016) (Zdenek, Kvizda, Nigrin, & Seidenglanz, 2014). Preston (2008) cites too thin demand in most markets along with economies of scale and density as reasons to assume that the number of actors in this type of market will be very limited. As far as we know, however, this has not been proven.

It is therefore interesting to study a situation where there is nothing in particular that hinders the number of operators on a market to grow, but where both entrants and incumbents will add or remove departures depending on their total profitability is affected on the margin when adding one daily departure.

A first observation is that when entrants add departures, the profit of existing departures falls as a consequence both of increased price competition and falling average demand when passengers are spread more thinly. Therefore, the marginal profit of adding an extra departure is lower for an incumbent compared to an entrant. Assume that no operator is large enough to form pseudo-monopoly situations as described in section 4.2, and that instead the smallest operator always has the least to loose from adding new departures. In equilibrium, each operator will run a single departure, and the number of departures (and operators) is the highest possible that permit them all to be profitable. (If one departure was unprofitable, that operator would exit the market, and equilibrium would be restored.)

Using the parameters of our base case, there will be 15 operators, increasing the number of departures either by half or threefold compared to the Nash and Stackelberg equilibriums, respectively. Total welfare increases by 60-70% by the same comparison, and profits fall sharply to perhaps as little as 10-15 % of the duopoly level. These results are sensitive to variations of parameter values, however.

5. Conclusions

The model presented in this paper is built on the hypothesis that competition occurs between nearby departures. This has large implications for the results. It affects the operators' best strategies, and hence it affects prices, profit, ridership and social welfare. It is clear that if the hypothesis is true, then any model that does not take account of it will fail to describe the market properly.

Results provided by the simulation model proposed in this article indicate that a stable equilibrium point with two independent operators exists on a railway market with on-rail competition, provided that it is possible through legal means to stop one operator from buying the other's access rights. Profits do not decrease towards zero in this point.

If it is not possible to hinder operators from buying and selling access rights then there are incentives for one operator to buy all access rights at a price that its competitor would accept, thus restoring monopoly.

Social welfare increases when competition successfully replaces profit-maximising monopoly. This result is less stable if one looks only at the domestic part of social welfare however, as profits that previously stayed in the country may be transferred abroad when operators are not government-owned.

Attempts by the regulator to recover high profits to state coffers by introducing high infrastructure charges lowers total welfare, as it pushes operators to a new equilibrium point in the frequency game, with fewer departures and higher fares.

The equilibrium tends to be asymmetrical in the sense that one operator offers a substantially larger number of departures than the other, while selling tickets at higher prices. Noteworthy is that this result appears even when operators' preconditions are perfectly symmetric, that is when excluding the effects of reputation with customers, efficiency of sales channels, quality of service and economies of scale and scope.

Welfare maximum under price competition is symmetric, to the contrary. It is optimal when operators offer equally many departures. This constrained optimum may not be possible to reach through regulatory means however. Policies studied in this paper that are designed to produce equally many departures end up either failing through not providing sufficient incentives for the smaller operator to raise frequency, or damaging total welfare by lowering combined frequency or raising average fares.

If the frequency game results in Stackelberg equilibrium, this benefits both operators compared to the Nash equilibrium. Total welfare is lower in the Stackelberg equilibrium point however.

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