Welfare Costs of Coordinated Infrastructure Investments: The Case of Competing Transport Modes

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Abstract

Infrastructure investments such as in rail and road networks are often undertaken by different parties that have differing degrees of vertical integration into downstream rolling stock (i.e. train and truck) investments. We analyse the impacts on freight transport and welfare outcomes of different institutional approaches to investment coordination across multiple freight modes (rail and road) in the presence of upstream and downstream cost-reducing investments in each mode. We show that welfare is reduced when a profit-maximising transport infrastructure investor correctly anticipates the advent of a future competing infrastructure. This is because myopically failing to anticipate future competition results in welfare-enhancing over-investment. We further show that presciently anticipating inter-modal competition is not solely responsible for reduced welfare, with additional vertical and horizontal coordination issues also at work. Our model can be applied to a range of applications that deal with multiple competing infrastructure investments.

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1 Introduction

The New Zealand government (including both central and local government) effectively forms a holding company over a range of transport infrastructure assets. Roads, rail and rolling stock (on rail) are owned by central government, ports are owned (wholly or in part) by local government (NZPC, 2012), while trucks and ships are owned privately. Existing inland ports are owned by the major port providers (Fabling et al., 2013), a number of airports are wholly or in part owned by local or central government, while central government has majority ownership of the country's major airline. Government plays a major role in the funding of ultra-fast broadband, a potential rival technology to these transport infrastructures. This situation is not unique: governments have similar holding company-type roles across multiple competing infrastructure sectors in many countries.

Given these ownership structures, we analyse the impacts of alternative institutional and decision-making structures across government infrastructure providers.[1] Specifically, we focus on a two-sector freight model (road and rail) where government owns both the roads and the rail tracks plus the rail rolling stock, while a private sector operator owns the trucks. The analysis highlights the implications of coordinated versus uncoordinated decision-making by the road and rail infrastructure providers.

Our paper differs from a number of recent descriptive reports on New Zealand freight transportation that take the existing institutional structures for the transport infrastructure providers as given (for instance: PwC, 2012; UNISA, 2013). Few of the papers that describe and forecast freight traffic within New Zealand analyse the strategic interactions that may occur between infrastructure and freight providers.[2] The absence of existing analyses

[1] NZPC (2012) describes the existing institutional structures – including differing objectives – of road, rail and other infrastructure providers. While the New Zealand Railways Corporation (KiwiRail) is a state-owned enterprise (SOE), it has mixed (profit plus public good) objectives. Rail is expected to deliver a return on capital invested while road investments are charged on a pay-as-you-go (PAYGO) basis. NZPC highlights the existing lack of coordination across modes in terms of investment decisions, while discussing the governance and information difficulties that may arise with greater coordination.

[2] An exception is the unpublished PhD thesis of Hyun Chan Kim (2014) who investigates substitutability issues in New Zealand freight using revealed and stated preference data of New Zealand shippers.

of strategic interactions across freight sectors provides the motivation for our analyses of these strategic interactions.

The literatures with models closest to our own include those on strategic R&D investments (e.g. Spencer and Brander, 1983), and those on cost-reducing investments with asymmetric vertical integration (e.g. Buehler and Schmutzler, 2008; Meade, 2011). The former analyses cost-reducing R&D investments made either simultaneously or sequentially by firms which subsequently compete in quantities. In the case that firms make sequential investments rather than simultaneous, each investing firm fully anticipates how its investment choice affects subsequent investment or output choices. The latter literature analyses cost-reducing investments by either downstream or upstream firms in vertical industries featuring asymmetric vertical integration (i.e. an integrated firm competing with vertically separated firms).

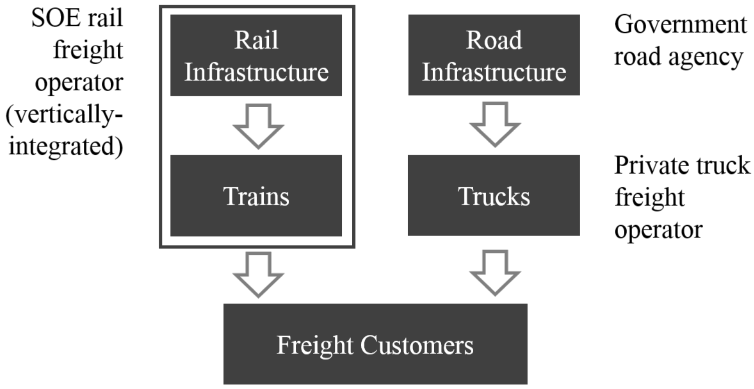
By contrast, we analyse both upstream and downstream cost-reducing investments, and do so under asymmetric integration. We also analyse sequential upstream investment choices. We do so for the case in which the investing firm fully anticipates the impact of its choice on subsequent investment and output choices. We also do so for the case in which it makes its investment choice myopically, not anticipating subsequent strategic investments and output choices by a rival. To the best of our knowledge, ours is the first study to compare myopic upstream investment with non-myopic upstream investment. It is also the first to consider sequential upstream investments followed by simultaneous downstream investments, under asymmetric integration. Furthermore, we compare outcomes under these institutional structures with the welfare optimum of a social planner.

Section 2 of the paper outlines our model. Section 3 solves the model, firstly assuming no coordination between the road and rail infrastructure providers, and subsequently assuming a coordinated approach. Section 4 analyses the impacts of coordinated versus uncoordinated investment on several welfare and other metrics, and also compares these outcomes with the social optimum. Section 5 provides brief conclusions and discusses several potential extensions to our basic model.

2 Setup

We model transport investment coordination for freight delivery services, treating such services as being homogeneous. Our Cournot duopoly model has three actors. The first is a vertically-integrated and profit-maximising state-owned enterprise (SOE). It invests in both rail infrastructure (e.g. rail tracks) and rolling stock (e.g. trains), and operates that rolling stock to

Figure 1: Freight Services Industry Configuration



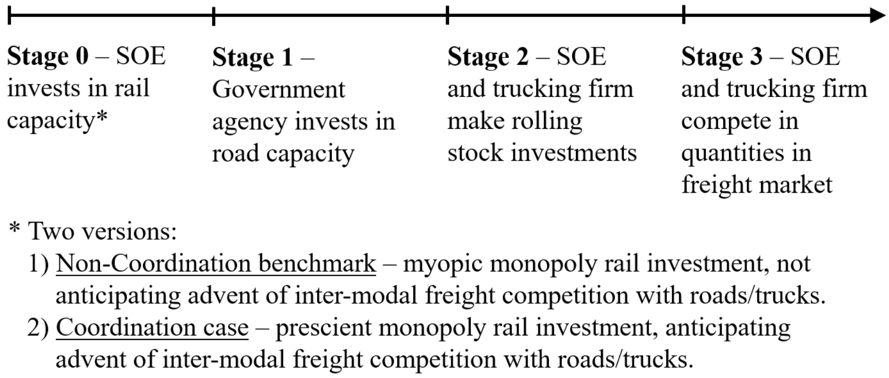
deliver freight. The second is a vertically-separated and profit-maximising truck company that invests in trucks, pays road-user charges to use roads, and operates its trucks to compete with the SOE in freight delivery. The final actor is a government agency that constructs roads, and charges the truck company for their use on a cost-recovery basis. This industry configuration is illustrated in Figure 1.

We model transport infrastructure investment as investments in rail and road capacity that affect the marginal costs of operating trains and trucks respectively. We further model rolling stock investments – i.e. investments in trains and trucks – as cost-reducing investments in each technology. Thus both types of investment affect the cost-competitiveness of each freight mode. For example, smoother rail tracks or wider roads enable higher-speed freight movement. Likewise, given rail and road capacities, rolling stock operators can make investments affecting rolling stock efficiency, such as by buying more fuel-efficient trucks or trains.

The timing of the game, illustrated in Figure 2, is as follows (using subscripts l for rail, d for road, n for train, and k for truck):

- *Stage 0* – The SOE invests in rail capacity X_l, incurring investment cost $\frac{1}{2}X_l^2$.
- *Stage 1* – The government agency invests in road capacity X_d, incurring investment cost $\frac{1}{2}X_d^2$ (which it recovers from the truck company as a fixed charge).
- *Stage 2* – The SOE makes train cost-reducing investment β_n at cost $\frac{1}{2}\beta_n^2$, and the truck company simultaneously makes truck cost-reducing investment β_k at cost $\frac{1}{2}\beta_k^2$.

Figure 2: Timing



- *Stage 3* – The SOE and truck company compete in quantities q_n and q_k respectively to deliver freight.

Inverse demand for freight delivery is $p(q_n, q_k) = 1 - q_n - q_k$, where p is the common price per unit of freight service provided by either train or truck. We normalise rail and road operating costs to nil, with the marginal cost of operating train-based freight services being:

$$c_n = B_n - \beta_n - \alpha_l X_l \tag{1}$$

Here B_n is the "intrinsic" marginal cost of operating train-based freight services, and we assume a scale parameter $\alpha_l \in (0, 1]$. Thus the marginal cost of operating train-based freight services is the intrinsic operating cost B_n less investment in train efficiency β_n, and further less the impact of rail capacity investment on rolling stock efficiency $\alpha_l X_l$. Similarly, the marginal cost of operating truck-based freight services is:

$$c_k = B_k - \beta_k - \alpha_d X_d \tag{2}$$

with B_k, β_k and α_d defined analogously.

We model two transport infrastructure investment scenarios. The first, representing infrastructure investment "coordination", assumes that the SOE's rail investment choice in Stage 0 fully anticipates duopoly competition with the truck firm in the subsequent game stages. Hence we refer to this as the "prescient monopoly" case, in that the SOE's monopoly choice of rail infrastructure is made anticipating inter-modal competition from trucking.

The second transport infrastructure investment scenario, representing "non-coordination" in infrastructure investment, is assumed to reflect the status quo. It represents rail infrastructure as a legacy from historical investment decisions made by a monopoly rail operator before the advent of trucking. More specifically, we assume that the SOE's choice of rail infrastructure is made in Stage 0 supposing that the SOE expected to remain a monopoly in Stages 2 and 3, and that there is no Stage 1. However, having chosen this legacy level of rail infrastructure, the SOE then continues through Stages 1 through 3 as above, with the advent of trucking "unexpectedly" arising subsequent to its rail investment. Hence we refer to this as the "myopic monopoly" case, since the SOE's monopoly choice of rail infrastructure is made without anticipating the advent of inter-modal competition.[3]

3 Solution

The game is solved by backward induction, finding the subgame perfect equilibrium in each stage. We begin by solving the status quo case of non-coordination under myopic monopoly, and then solve for the coordination case under prescient monopoly. The impact of transport infrastructure investment coordination is then measured as equilibrium values under coordination less their corresponding value under non-coordination.

3.1 Non-Coordination Benchmark – Rail Investment Not Anticipating Inter-modal Competition (Myopic Monopoly)

In the status quo scenario, the SOE's profit function comprises profits from delivering freight quantity q_n by train, less the cost of making cost-reducing investments β_n in trains, and also less the cost of investing in rail capacity X_l. Not anticipating the advent of inter-modal competition by trucking, this writes as:

$$\pi_{SOE} = (p - c_n)\, q_n - \frac{1}{2}\beta_n^2 - \frac{1}{2}X_l^2$$

Substituting for c_n, and for p in the case that $q_k = 0$ (i.e. assuming the myopic case in which no competing freight delivery by trucks is anticipated), that is:

$$\pi_{SOE} = ((1 - q_n) - (B_n - \beta_n - \alpha_l X_l))\, q_n - \frac{1}{2}\beta_n^2 - \frac{1}{2}X_l^2 \qquad (3)$$

[3] At the margin, the opposite investment timing may currently sometimes be the case, with (uncoordinated) road investments being taken myopically in advance of rail investments. Nevertheless, the analytical issues are comparable.

In Stage 3, the SOE chooses q_n to maximise π_{SOE}, taking its past investments β_n and X_l as given. This yields the myopic monopoly output:

$$q_n^{MM}(\beta_n, X_l) = \frac{1}{2}(1 - (B_n - \beta_n - \alpha_l X_l)) \tag{4}$$

In Stage 2, it chooses β_n to maximise π_{SOE} anticipating $q_n^{MM}(\beta_n, X_l)$ and taking X_l as given. This yields:

$$\beta_n^{MM}(X_l) = 1 - (B_n - \alpha_l X_l) \tag{5}$$

Since the myopic monopoly does not anticipate the advent of trucking, Stage 1 is ignored and the SOE then just chooses its profit-maximising rail capacity X_l, anticipating $\beta_n^{MM}(X_l)$ and $q_n^{MM}\left(\beta_n^{MM}(X_l), X_l\right)$. This yields:

$$X_l^{MM} = \frac{\alpha_l (B_n - 1)}{\alpha_l^2 - 1} \tag{6}$$

3.2 Coordination Case – Rail Investment Anticipating Inter-modal Competition (Prescient Monopoly)

3.2.1 Stage 3 – Optimal Freight Outputs

Anticipating inter-modal competition, the SOE's profit function writes as:

$$\pi_{SOE} = ((1 - q_n - q_k) - (B_n - \beta_n - \alpha_l X_l))\, q_n - \frac{1}{2}\beta_n^2 - \frac{1}{2}X_l^2 \tag{7}$$

In Stage 3, the SOE chooses q_n to maximise π_{SOE}, taking its investments β_n and X_l as given, and also taking its trucking rival's freight output q_k as given. This leads to its best response function in terms of q_k:

$$q_n(q_k; \beta_n, X_l) = \frac{1}{2}(1 - (B_n - \beta_n - \alpha_l X_l) - q_k)$$

In contrast, the trucking firm profit writes as its profit from delivering freight quantity q_k by truck, less the cost of making cost-reducing investment β_k in trucks, and also less the lump-sum cost it faces from the government road agency for using roads. That is:

$$\pi_k = (p - c_k)\, q_k - \frac{1}{2}\beta_k^2 - \frac{1}{2}X_d^2$$

Substituting for p and c_k:

$$\pi_k = ((1 - q_n - q_k) - (B_k - \beta_k - \alpha_d X_d))\, q_k - \frac{1}{2}\beta_k^2 - \frac{1}{2}X_d^2 \tag{8}$$

In Stage 3, the trucking firm chooses q_k to maximise π_k, taking its investmentβ_k and the government agency's investment X_d as given, and also taking its rival's freight output q_n as given. This leads to its best response function in terms of q_n:

$$q_k\left(q_n; \beta_k, X_d\right) = \frac{1}{2}\left(1 - \left(B_k - \beta_k - \alpha_d X_d\right) - q_n\right)$$

Simultaneously solving the two firms' reaction functions results in the Stage 3 subgame perfect equilibrium freight outputs for the prescient monopoly case:

$$\begin{aligned} q_n^{PM}\left(\beta_n, \beta_k, X_l, X_d\right) &= \tfrac{1}{3}\left(1 + \left(B_k - \beta_k - \alpha_d X_d\right) - 2\left(B_n - \beta_n - \alpha_l X_l\right)\right) \\ q_k^{PM}\left(\beta_n, \beta_k, X_l, X_d\right) &= \tfrac{1}{3}\left(1 + \left(B_n - \beta_n - \alpha_l X_l\right) - 2\left(B_k - \beta_k - \alpha_d X_d\right)\right) \end{aligned} \tag{9}$$

Each firm's freight output is increasing in its rival's marginal cost, but decreasing more strongly in its own marginal cost. This means it is decreasing in its rival's cost-reducing investment, but increasing more strongly in its own such investment. Likewise, all other things being equal (i.e. α_l and α_d), each firm's freight output is decreasing in the investment made in its rival's infrastructure, but increasing more strongly in the investment made in its own infrastructure.

3.2.2 Stage 2 – Optimal Rolling Stock Cost-Reducing Investments

Anticipating the above optimal freight outputs, in Stage 2 the SOE chooses its train cost-reducing investment β_n to maximise π_{SOE}, taking infrastructure investments X_l and X_d as given, and taking also its trucking rival's cost-reducing investment β_k as given. This leads to its best response function in terms of β_k:

$$\beta_n\left(\beta_k; X_l, X_d\right) = 4\left(1 - 2\left(B_n - \alpha_l X_l\right) + \left(B_k - \beta_k - \alpha_d X_d\right)\right)$$

Likewise, the trucking firm chooses β_n to maximise π_k taking X_l and X_d as given, and taking also β_n as given. This leads to its best response function:

$$\beta_k\left(\beta_n; X_l, X_d\right) = 4\left(1 - 2\left(B_k - \alpha_d X_d\right) + \left(B_n - \beta_n - \alpha_l X_l\right)\right)$$

Solving these simultaneously yields the Stage 2 subgame perfect equilibrium rolling stock cost-reducing investments of each firm, as functions of infrastructure capacities:

$$\begin{aligned} \beta_n^{PM}\left(X_l, X_d\right) &= \tfrac{4}{5}\left(1 + 2\left(B_n - \alpha_l X_l\right) - 3\left(B_k - \alpha_d X_d\right)\right) \\ \beta_k^{PM}\left(X_l, X_d\right) &= \tfrac{4}{5}\left(1 + 2\left(B_k - \alpha_d X_d\right) - 3\left(B_n - \alpha_l X_l\right)\right) \end{aligned} \tag{10}$$

Hence, all other things being equal, each firm's cost-reducing investment choice is decreasing in its own infrastructure capacity, but more strongly increasing in its rival's infrastructure capacity. In other words, each firm must invest in more efficient rolling stock the greater is its rival's infrastructure capacity. Conversely, it makes a lower investment in rolling stock the higher is its own infrastructure capacity. Thus a freight firm's competitiveness is determined by both its rolling stock choice, and the choice of its infrastructure capacity. The latter choice is its own if it is vertically integrated, as for the rail freight SOE, or made by a vertically separate entity otherwise (i.e. the government road agency in the case of trucking).

3.2.3 Stage 1 – Optimal Investment in Road Capacity

The government agency that invests in road capacity X_d is assumed to do so to maximise total surplus, anticipating the subgame perfect equilibria in Stages 2 and 3, and taking rail capacity as given. Since the cost of road investment is fully recovered from the trucking firm as a lump-sum road-user charge, total surplus writes simply as:

$$W\left(X_l, X_d\right) = \pi_{SOE}\left(X_l, X_d\right) + \pi_k\left(X_l, X_d\right) + CS\left(X_l, X_d\right) \tag{11}$$

Here net consumer surplus from freight services, CS, is computed as:

$$CS = \int_0^{q_n+q_k} p\left(Q\right) dQ - p\left(q_n, q_k\right)\left(q_n + q_k\right)$$

which, after substituting for $p\left(q_n, q_k\right)$ and evaluating, simplifies as:

$$CS\left(q_n, q_k\right) = \frac{1}{2}q_n^2 + q_n q_k + \frac{1}{2}q_k^2 \tag{12}$$

By substituting the Stage 2 subgame perfect equilibrium values for rolling stock investments into the Stage 3 subgame perfect equilibrium values for freight quantities, we can then express $CS\left(q_n, q_k\right)$ in terms of just X_l and X_d, i.e. $CS\left(X_l, X_d\right)$.

After computations it can be shown that the government agency's surplus maximum is achieved for:

$$X_d\left(X_l\right) = \frac{\alpha_d\left(7B_k - 3\left(B_n - \alpha_l X_l\right) - 4\right)}{7\alpha_d^2 - 5} \tag{13}$$

3.2.4 Stage 0 – Prescient Monopoly's Investment in Rail Capacity

Anticipating the subgame perfect equilibria in Stages 1 through 3, the SOE finally chooses X_l to maximise π_{SOE}, yielding:

$$X_l^{PM} = \frac{2\alpha_l\left(\alpha_d^4\left(B_n-1\right)+3B_k\left(\alpha_d^2-2\right)+4B_n\left(1-\alpha_d^2\right)+\alpha_d^2+2\right)}{2\alpha_d^4\alpha_l^2-49\alpha_d^4-8\alpha_d^2\alpha_l^2+70\alpha_d^2+8\alpha_l^2-25} \tag{14}$$

This compares with the optimal rail investment under myopic monopoly derived earlier (equation (6)):

$$X_l^{MM} = \frac{\alpha_l\left(B_n-1\right)}{\alpha_l^2-1}$$

Notice that the equilibrium value of rail investment under coordination depends on cost parameters for both trains and trucks, without having assumed any form of interaction between infrastructure investments or between rolling stock cost-reducing investments. This is a consequence of the assumed Cournot competition between modes in the freight market in Stage 3. This results in subgame perfect equilibrium freight outputs that depend on investments in both modes. As a consequence, this dependency is reflected in subgame perfect equilibria in all preceding stages, including for rail investment in Stage 0.

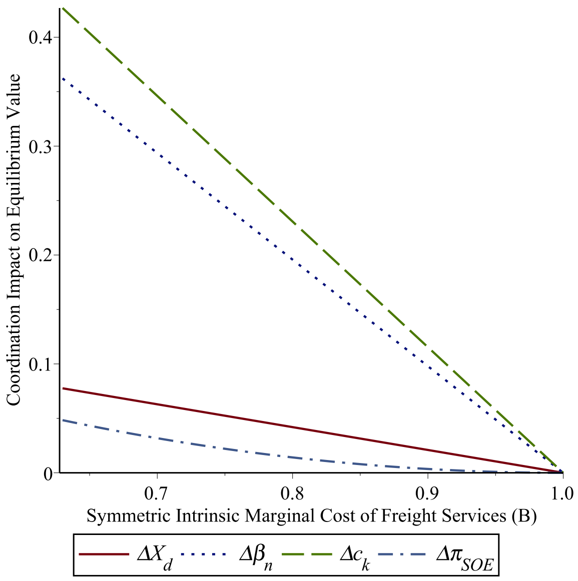
4 Impact of Coordinated Rail Investment

4.1 Prescient Monopoly vs Myopic Monopoly

With X_l^{PM} and X_l^{MM} derived above it is possible to compute the duopoly equilibrium values of X_d, β_n and β_k, and q_n and q_k for two scenarios – one in which rail capacity was chosen by a myopic monopoly (X_l^{MM}), and the other in which it was chosen by a prescient monopoly (X_l^{PM}). This then allows computation of performance measures such as train and truck marginal costs c_n and c_k, profits of the SOE and trucking firm, π_{SOE} and π_k, as well as net consumer surplus CS and total surplus W, in each scenario. In this section we discuss how these duopoly values change by moving from myopic to prescient rail investment.

We impose restrictions on parameter values in order to more clearly illustrate the impact of rail investment being made in anticipation of inter-modal freight competition between trains and trucks. Specifically, we impose symmetry on the SOE and trucking firm, with the proportionate impact of infrastructue capacity on marginal cost becoming $\alpha_l = \alpha_d = \alpha$ and the intrinsic

Figure 3: Positive Changes in Equilibrium Variables with Coordinated Rail Investment



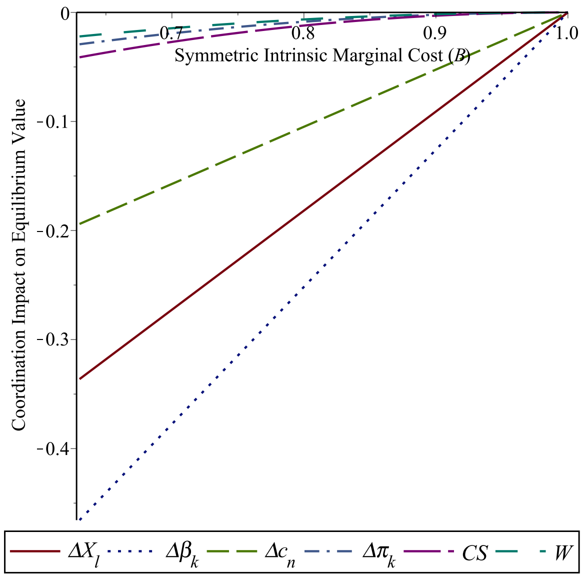
marginal cost of offering freight services becoming $B_n = B_k = B$. Imposing $\alpha = \frac{1}{2}$ is sufficient to ensure that all second order conditions are satisfied, while imposing $0.63 \leq B < 1$ is sufficient to ensure that $0 \leq c_i < 1$ for $i \in \{n, k\}$. The upper limit on c_i is chosen to ensure that the freight market is served (since the vertical intercept of inverse demand is 1).

Figures 3 and 4 illustrate changes in model outputs due to moving from non-coordinated rail investment (i.e. using subgame perfect equilibrium values in Stages 1 through 3 based on X_l^{MM}) to coordinated investment (based on X_l^{PM} instead).

As can be seen, for the chosen parameter values rail investment X_l is lower when inter-modal competition is anticipated than when it is not. This reflects the SOE capturing a smaller share of the cost-efficiencies resulting from its rail investment when later having to compete with trucking in the freight market. Conversely, road investment X_d is higher under coordination, with lower rail investment making trains a less efficient competitor in the freight market, increasing the returns to making trucks more efficient competitors.

Due to lower rail investment under coordination, the SOE must make a larger investment β_n in rolling stock efficiency in order to retain cost efficiency. Conversely, higher road infrastructure means the trucking firm can afford to make a lower investment β_k in rolling stock efficiency. Together, these differences in infrastructure and rolling stock efficiency investments

Figure 4: Negative Changes in Equilibrium Variables with Coordinated Rail Investment



translate into higher truck marginal cost c_k, and lower train marginal cost c_n, under coordination.

In terms of profits, rail investment coordination results in higher SOE profits π_{SOE}, but lower trucking firm profits π_k. The SOE's profit benefits from both lower rail investment cost and lower train marginal cost, while the trucking firm's profit is reduced by a higher road-user charge (i.e. road investment cost) and higher truck marginal cost. Whereas coordinated rail investment implies a Stackelberg leadership advantage to the SOE, this is not the case with non-coordinated investment. The difference arises because the SOE rationally anticipates the government agency's optimal road capacity choice and trucking firm's optimal cost-reducing investment under coordination, but not under non-coordination.

Finally, rail investment coordination results in lower CS, implying a fall in total freight output and hence increase in freight price. This decline in CS, coupled with a decline in trucking firm profits, is sufficient to outweigh the SOE's increased profits, resulting in reduced total surplus W. In standard Stackelberg models, one firm having a leadership role disadvantages its rival but benefits consumers by expanding total output and hence reducing price. Here, however, this mechanism breaks down due to the road capacity choice not being made by either competitor in the freight market, but instead by a government agency seeking to maximise neither the SOE's nor the trucking firm's profit.

In summary, a consequence of non-coordinated legacy rail investment is an underinvestment in roads. This leads to more efficient trucks and less efficient trains than if there had been coordinated, and hence lower, rail investment. In turn, this implies lower truck marginal cost and higher train marginal cost as a consequence of a lack of rail investment coordination. In welfare terms, the legacy over-investment in rail capacity results in lower SOE profits, since rail investment was optimised without anticipating subsequent inter-modal competition in the freight market. On the other hand, it results in higher trucking firm profit, consumer surplus and total surplus.

4.2 Comparison with Social Optimum

Finally, it is worth comparing both the Prescient Monopoly and Myopic Monopoly Cases with the social planner's social optimum. A social planner would maximise gross consumer surplus S net of production and investment costs (both infrastructure and rolling stock). Here, for a first best total freight services market output q_{FB}, S writes as:

$$S = \int_0^{q_{FB}} (1 - Q)\, dQ = q_{FB} - \frac{1}{2} q_{FB}^2 \tag{15}$$

We assume the symmetric case with $\alpha_l = \alpha_d = \alpha$ and $B_n = B_k = B$ for comparison purposes. Investment costs are convex, so in this symmetric case investment costs are minimised by splitting freight services production and the corresponding required investment costs equally between the two modes (road and rail), rather than producing all freight services using just one mode. That is, variable production costs are:

$$TC = (B - \beta - \alpha X_l) \frac{q_{FB}}{2} + (B - \beta - \alpha X_d) \frac{q_{FB}}{2} \tag{16}$$

We do not force $X_l = X_d$ because, to reflect the information structure of the earlier setup, we continue to assume that timing is as before. That is, rail infrastructure investment precedes road infrastructure investment, rolling stock investments in each mode are then made simultaneously, and finally the freight services market is served. For our social optimum benchmark we assume the social planner is prescient, and therefore correctly anticipates the advent of road-based freight services.

With this setup the social planner maximises:

$$W_{FB} = S - TC - I_l - I_d \tag{17}$$

where the latter terms are investment costs for rail and road respectively, being:

$$I_i = \frac{1}{2}\beta^2 + \frac{1}{2}X_i^2 \qquad i \in \{l, d\}$$

Solving by backward induction as before, it can be shown that the welfare-maximising freight services output is:

$$q_{FB}\left(\beta, X_d, X_l\right) = 1 + \frac{\alpha}{2}\left(X_d + X_l\right) - \left(B - \beta\right) \tag{18}$$

This then leads to a socially-optimum rolling stock investment in each mode of:

$$\beta\left(X_d, X_l\right) = 1 + \frac{\alpha}{2}\left(X_d + X_l\right) - B \tag{19}$$

The planner's welfare-maximising road investment is thus:

$$X_d\left(X_l\right) = \frac{\alpha\left(2B - \alpha X_l - 2\right)}{\alpha^2 - 2} \tag{20}$$

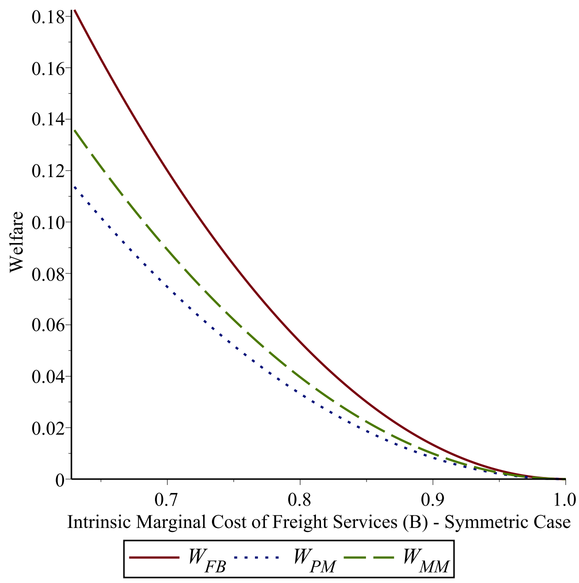
Finally, the planner chooses socially-optimal rail investment:

$$X_l = \frac{\alpha\left(B - 1\right)}{\alpha^2 - 1} \tag{21}$$

At this level of X_l we find that (20) yields $X_d = X_l$, as to be expected under our assumed symmetry. First order conditions remain satisfied for the parameter restrictions on α and B imposed in Section 4.1, so total welfare under First Best, Prescient Monopoly and Myopic Monopoly plot as in Figure 5.

Consistent with the findings in Section 4.1, welfare with infrastructure investment coordination (W_{PM}) is lower than when rail infrastructure is chosen myopically (W_{MM}). Furthermore, neither case generates as high a welfare as the social planner's First Best (W_{FB}, although these differences vanish as the "intrinsic" cost of providing freight services, B, rises). This is despite the planner acting with foresight as in the Prescient Monopoly case (i.e. correctly anticipating the advent of road-based freight delivery). Hence the welfare loss associated with coordinated infrastructure investment – in which the rail SOE correctly anticipates the advent of road-based freight services

Figure 5: First Best Total Welfare vs Prescient Monopoly and Myopic Monopoly Cases



competition – arises for reasons other than just the loss of welfare gains from myopic infrastructure investment. It also reflects a lack of vertical coordination between the road investment agency and the private truck operator (the former making investments affecting the latter's downstream investments, but with a different objective function).[4] It further reflects the lack of horizontal coordination between the SOE and both the roading agency (in terms of road infrastructure investments) and the private trucking firm (in terms of truck investments). Determining how to efficiently resolve these vertical and horizontal coordination issues is left to future work.

5 Conclusions

The task of coordinating investments in freight infrastructure across competing modes is difficult, as is evident in the incomplete coordination that has occurred across competing modes in New Zealand over recent decades. Our paper sheds some light on this problem in the context of a stylised model of two competing freight modes that undertake both upstream and downstream cost-reducing investments. We solve the model for the case where the initial

[4]This raises questions about the welfare implications of vertical separation between infrastructure and rolling stock investments, such as in the UK.

investment (by rail in this case) is made both with and without anticipation of subsequent road investment decisions. We show that the freight and welfare outcomes differ depending on the degree of investment coordination across modes.

Perhaps surprisingly, we find, in the context of this model, that uncoordinated investment yields a superior welfare outcome than does a coordinated approach. However our result reflects the assumption of profit-maximising rather than welfare-maximising choices by each infrastructure provider. The result may therefore be specific to this set of institutional assumptions. Indeed, our comparison with the social planner's problem reveals that neither coordinated nor uncoordinated profit-maximising choices yield the social optimum. Hence deeper vertical and horizontal coordination issues are also at play. These issues are in addition to the problem of correctly anticipating the advent of future competing infrastructures when making current infrastructure investments.

Our model could be extended and/or applied to a range of other situations. For instance, the objectives of either infrastructure provider could be altered to one of welfare-maximisation. A model could also allow for differing timing of decisions, for example having road investment occurring before rail investment or having investment decisions made simultaneously (with and without welfare-maximisation objectives). An extended model could allow for interactions between modes, for example with spill-over benefits (e.g. through cross-modal learning effects) or through complementarities (e.g. with rail routes connecting to particular road routes or ports). Another form of extension would be to allow for a trucking or train oligopoly (as opposed to the monopolies assumed here) and/or differentiated demand for truck and rail freight services. Further freight sectors (e.g. coastal shipping) could be added, or a competing mode to freight – such as ultra-fast broadband (which enables substitution of weightless services for material goods) – could be included. Finally, one could allow multiple modes to be vertically integrated (or separated), an extension that could be particularly germane if the analysis was extended to broadband services.

Each of these extensions is likely to produce differing freight and welfare outcomes to those modelled here. Our key contribution is to lay out a basic modelling framework and to show that in the context of competing infrastructure providers, the institutional structure does matter for outcomes of policy interest. Hence the choice of institutional structures (which yield materially different freight and welfare outcomes) should be considered when decisions are made about the structure and objectives of the government's overall 'infrastructure holding company'.

References

[1] Buehler, S. and A. Schmutzler, 2008, "Intimidating Competitors – Endogenous Vertical Integration and Downstream Investment in Successive Oligopoly", *International Journal of Industrial Organization*, 26, 247–265.

[2] Fabling, R., Grimes, A. and L. Sanderson, 2013, "Any Port in a Storm: Impacts of New Port Infrastructure on Exporter Behaviour", *Transportation Research E*, 49(1), 33–47.

[3] Kim, H. C., 2014, *Developing a Mode Choice Model for NZ Freight Transportation*, PhD Thesis (Civil Engineering), University of Canterbury.

[4] Meade, R., 2011, *The Effects of Vertical Integration, Forward Trading and Competition, on Investment and Welfare, in an Imperfectly Competitive Industry*, MPhil dissertation, Toulouse School of Economics.

[5] NZPC, 2012, *International Freight Transport Services Inquiry*, Wellington, New Zealand Productivity Commission (NZPC).

[6] PwC, 2012, *Upper North Island Port Study – How Can We Meet Increasing Demand for Ports in the Upper North Island?*, Report for the Upper North Island Strategic Alliance, Auckland, PricewaterhouseCoopers (PwC).

[7] Spencer, B. J. and J. A. Brander, 1983, "International R&D Rivalry and Industrial Strategy", *Review of Economic Studies*, 50(4), 707–722.

[8] UNISA, 2013, *Upper North Island Freight Story – Reducing the Cost of Doing Business in New Zealand through an Upper North Island Lens*, Auckland, Upper North Island Strategic Alliance (UNISA).