Where to open maritime containers?: A decision model at the interface of maritime and urban logistics

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Abstract: After an era of developing large-scale hinterland access for maritime containers by use of rail and inland waterways, research interest and practice has witnessed a slight shift towards port-centric logistics. The big question is where to open import containers and close and seal the ones for export goods. Is it better done in the port vicinity or should the maritime containers also be used for transport to and from the hinterland? In other words, where is the stuffing and stripping operations best located? Focusing on the import of goods loaded in maritime containers, this article provides a model for assessing the options of locating Distribution Centres (DCs) in the vicinity of the port or in the hinterland, or using a combination of the two. The model is illustrated by a case study of import through the Port of Gothenburg, Sweden, comparing a port-centric DC with a location in Falköping, 130 kms inland. Unless more than 85% of the shipments out of DCs are bound for Gothenburg and its vicinity, the assessment favours stripping the maritime containers in the DC in Falköping.

Keywords: distribution centre; container; hinterland; port; port-centric logistics.

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1 Introduction

The rise of containerisation is the most noticeable trend in international logistics over the past 60 years. The advent of containers has shaped globalisation by providing a standardised transport system worldwide. Containerisation applies the basic principle of unit loads that stipulates loading cargo into the container as early as possible in the transport chain and unloading it as close to the consignee as possible to benefit from the efficiency of transhipment, transport and good cargo protection. This explains why maritime containers are often used not only at sea but also for inland transport.

We can observe two trends in the development of inland transport of maritime containers. First, port authorities worldwide have developed ambitious strategies to foster hinterland intermodal transport, so as to move containers between the port and regional load centres, as examined by van den Berg (2015). For instance, until a few years ago, the landlord Port of Gothenburg (PoG) strongly emphasised the development of a rail container shuttle system for servicing the hinterland, which has led to that about 50% of the containers arrive or leave by train. This strategy speeds up the flow through the port, strengthens the port's market position in the hinterland and reduces truck transport in the surroundings of the port and therefore limits negative externalities (Craig et al., 2013; Bouchery and Fransoo, 2015). Hinterland intermodal transport has been extensively studied in the academic literature, from case studies to theoretical analyses of its development. We refer to Witte et al. (2019) for a recent literature review. Interested readers might refer to Roso et al. (2009), Rodrigue and Notteboom (2009), Bergqvist et al. (2010) or Monios and Wilmsmeier (2013) for more details about the development of hinterland intermodal transport.

The second trend in the inland transport of maritime containers relates to the concept of port-centric logistics, defined by Mangan et al. (2008) as the provision of distribution facilities and value-adding activities in the port area. Port-centric activities can involve value-adding activities to optimise inland transport without affecting the location of the shippers' distribution Centres (DCs). This includes transloading the cargo into semi-trailers or continental containers, palletisation, cargo consolidation and product customisation (such as labelling). However, shippers can also locate full-service DCs in the port surroundings. For instance, Heitz et al. (2020) identify a trend in which new warehouses are increasingly either established in close proximity to the PoG, some of which built, owned and let out by PoG, or in neighbouring cities at a distance of more than 50 kms away from the port. The study found very few warehouse establishments in the area in-between, hence observing a geographical polarisation. This shows that the PoG is additionally developing a strategy to increase the flow through the port by establishing and owning warehouses in the port vicinity. Hence, it extends its role as landlord to include warehouses outside the port gates. We refer to Mangan et al. (2008), Pettit and Beresford (2009), Monios and Wilmsmeier (2012), Monios et al. (2016) and Monios et al. (2018) for further details on port-centric activities.

Those two trends, often concurrently promoted by port authorities, imply that shippers now have more options for deciding on where to locate their operations. The purpose of this article is to analyse the most suitable location for stripping import containers, or equivalently, for operating a DC. We do this by making use of both analytical and empirical approaches. After a literature review, we apply 1) a model-based approach with extensive explanation of assumptions and logical connections between parameters and 2) an exploratory approach based on a case study with empirical data in the setting of import to Sweden through PoG discussing the implications of the model.

This study requires a new focus on logistics by taking an overall perspective on inbound flows, warehousing operations and outbound flows. We define the geographical options for such types of activities and we develop a model to assess the performance of those options for different settings. This enables us to discuss the pros and cons of opening maritime containers in the port vicinity or farther into the hinterland. We highlight a variety of arguments for where to locate container stripping activities and we describe some patterns along commodity and distribution channels. Our analysis provides some insights into "where to inject the air" into distribution chains, that is where to divide a dense container shipment into smaller shipments on pallets, roll cages or in cartons ready to be delivered to industries, shops and individuals. Besides the theoretical model development, our analysis is conducted based on the empirical context of the major gateway port of Sweden, namely the PoG, and key inland locations in relation to the PoG.

In this article, we posit that the location of stuffing and stripping operations greatly affect vehicle flows in port cities and the efficiency of transport chains. Therefore, the question of where to open maritime containers is likely to catch the interest of urban and traffic planners, warehouse developers and logistics managers. This question also enables reconciling port and maritime logistics with urban logistics. We acknowledge the challenges related to our ambition, and our contribution is a first attempt towards a better understanding of the options faced by shippers when deciding where to open maritime containers. The activities performed in the DCs involve preparing the cargo for reaching the final customer (palletisation, deconsolidation, order picking and repackaging). This means, as argued above, that a lot of air is injected into the transport chain when the cargo comes closer to the final customer. This is a major cause of congestion in many cities. Therefore, we believe that a new focus is required that takes into account the overall perspective on inbound flows, warehousing operations and outbound flows.

Our contribution is threefold. First, from our knowledge, we propose the first model assessing the geographical options available for container stripping. We derive analytical results to identify the best option for maritime container stripping. Second, we evaluate the performance of those options for different settings and we derive a series of insights on the pros and cons of the options. Third, we propose an application of the model to the port city of Gothenburg and its surroundings.

We organise the rest of the article as follows. Section 2 reviews the related literature and helps to better position our contribution. Section 3 presents the context of our case study. Section 4 proposes a description of our analytical model and a discussion on the underlying assumptions. The main analytical results and general insights are delivered in Section 5 together with the results obtained from the case study. Finally, Section 6 highlights our main conclusions and some potential future research directions. All mathematical proofs can be found in Appendix A.

2 Literature review

Our contribution lies at the intersection of different research areas. We provided an overview of the literature related to intermodal hinterland transport and port-centric logistics in the introductory section. Here, we supplement this overview by analysing the literature on distribution logistics and urban logistics to position our contribution.

2.1 Distribution logistics

Distribution logistics includes all activities involved in the shipment of finished goods from production facilities to final points of consumption. Distribution logistics is characterised by specific challenges such as relatively high costs and the proximity to final customers. Therefore, distribution logistics and physical distribution has been widely studied in the literature. We refer to Hesse and Rodrigue (2004) for an overview of the development and importance of distribution logistics.

One of the traditional key questions related to distribution logistics concerns the structure of the distribution chain, including locational decisions for distribution facilities. The research on distribution logistics is scattered between different disciplines. For instance, in a recent review, Onstein et al. (2019) identified the relevant streams of research as being the areas of supply chain management, freight transport and geography. The field of supply chain management takes the perspective of shippers and focuses mainly on prescriptive analytical models. Researchers have proposed a substantial number of models related to DC location decision, see e.g., Jayaraman (1998), Nozick and Turnquist (2001), Oum and Park (2004), Klose and Drexl (2005), Revelle et al. (2008), Melo et al. (2009) and references therein. The contributions within this field also include multi-criteria decision making methods that enables identifying the most suitable location out of a list of options (see e.g., Kuo, 2011; Farahani and Asgari, 2007). Note also that some recent contributions mix several approaches. For instance, Halim et al. (2016) used a combination of multi-objective optimisation models with an assignment model to study port-hinterland distribution network design.

The research on freight transport takes the perspective of Logistics Service Providers (LSPs) and focuses mainly on descriptive models aimed at better understanding and forecasting the development of distribution logistics. We refer to Friedrich et al. (2014) for a recent review of the field. Transport geography takes a society perspective and focuses mainly on analysing location patterns and trends. The results enable highlighting some key features related to accessibility (Verhetsel et al., 2015; Holl and Mariotti, 2018), labour and land conditions (Hesse, 2004; Woudsma et al., 2008; McLeod et al., 2018) and logistics clusters (van den Heuvel et al., 2013; Olsson and Woxenius, 2014; Hylton and Ross, 2018).

2.2 Urban logistics

More than half of the world's population now lives in cities, and this share is expected to grow substantially in the coming decades. Cities are at the same time efficient and agile as well as amazingly complex. Therefore, apprehending urban logistics, also referred to as city logistics or urban freight, is a challenging task and the related literature is vast. We intend here to give a brief and partial overview of some issues related to urban logistics. We refer to Diziain et al. (2012), Arvidsson et al. (2013), Dablanc et al. (2013), Taniguchi et al. (2014), Behrends (2016), Hesse (2016), Savelsbergh and Van Woensel (2016) and Tsiulin et al. (2017) for some recent in-depth overviews of urban logistics. Our review focuses mainly on three aspects particularly relevant for positioning our contribution.

First, last-mile deliveries have attracted a lot of attention in recent decades. Several issues have been studied, such as the impact of e-commerce on last-mile delivery (Lee and Whang, 2001; Visser et al., 2014; Allen et al., 2018); the opportunity to establish urban consolidation centres (Allen et al., 2012; Nordtømme et al., 2015; Kin et al., 2016); the environmental evaluation of last-mile distribution strategies (Edwards et al., 2010; Brown et al., 2014); and the use of crowdsourcing-based solutions (Wang et al., 2016; Devari et al., 2017; Frehe et al., 2017; Arslan et al., 2018). We also note a recent interest in the so-called final 50 feet of last-mile delivery (Goodchild and Ivanov, 2017; Kim et al., 2018).

Second, the transport geography community has documented the removal of warehouses away from urban centres. This trend, referred to as 'urban logistics sprawl', has been highlighted for many large cities around the world (see Cidell, 2010, and references therein). The impact of urban logistics sprawl has been evaluated for different regions of the world (Dablanc and Rakotonarivo, 2010; Bart, 2010; Aljohani and Thompson, 2016) and several articles identify differences amongst cities in terms of urban logistics sprawl and propose some possible explanations (Dablanc et al., 2014; Kang, 2020; Heitz et al., 2020).

Third, we notice that the majority of the largest cities worldwide are located in coastal areas, often where rivers reach the ocean. These megacities are also often large ports, making the studies of port cities clearly relevant (Ducruet and Lee, 2007; Jung, 2011; Deng et al., 2013; Akhavan, 2017). One of the most studied aspects in port cities are the possible synergies and tensions between port activities and city development (World Bank, 2017; Browne and Woxenius, 2019). We refer to Zhao et al. (2017) and references therein for more details on the impact of port activities on urban competitiveness.

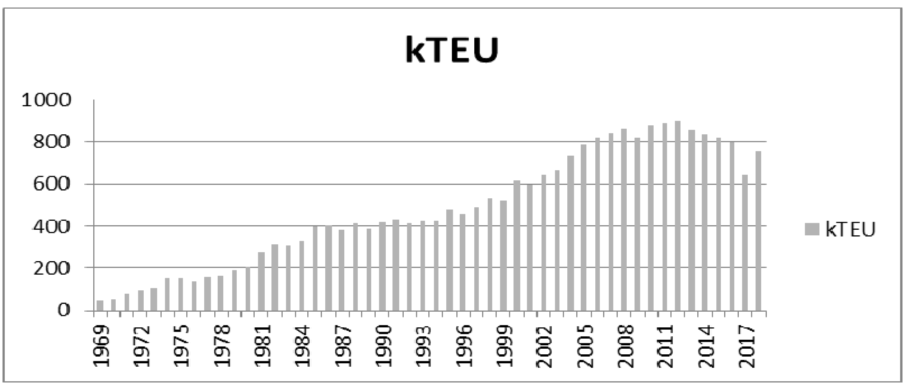
The large stream of literature on distribution logistics helps us by highlighting the main challenges faced by shippers. Additionally, we notice that urban logistics encompasses a wide variety of challenges in a rapidly evolving landscape. This explains why the literature on urban logistics has exploded during the past few decades. While distribution logistics focuses mainly on companies' strategic, tactical and operational decisions related to distribution, urban logistics tends to take an urban planning and transport economics perspective. These two streams of literature suggest that shippers face new challenges related to urban logistics and to the rise of new distribution channels. Our contribution builds from these fields and takes another perspective on distribution and urban logistics by connecting port logistics to last-mile deliveries.

The next section gives a detail account of the case study of import through the Port of Gothenburg, Sweden, comparing a port-centric DC with a location in Falköping, 130 kms inland. Subsequently, we develop an analytical model and we apply it in order to assess the options of locating DCs in the vicinity of the port or in the hinterland, or using a combination of the two.

3 Case study

The empirical context of this analysis is Sweden, a market characterised by a large geographical area and small population and hence a low population density. This leads to long distances and a challenge for distribution. Much of the inbound containers are concentrated at PoG, the largest port in Scandinavia with a market share of containers in Swedish ports of about 45% (Swedish Confederation of Transport Enterprises, 2018). Figure 1 illustrates the number of containers handled at PoG since 1969. The PoG has seen a substantial loss of handled containers during a recent labour conflict (Gonzalez-Aregall and Bergqvist, 2019), but volumes grew in 2018.

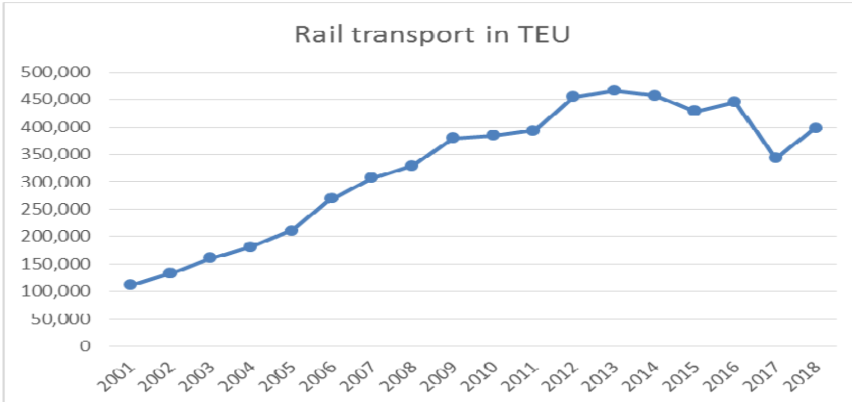
Figure 1 Container volume development for Port of Gothenburg 1969–2017



Source: Modified from Port of Gothenburg (2018a)

Another illustrative fact about the Port of Gothenburg is the high concentration of rail transport related to hinterland transport of containers. Rail was used for moving containers inland already at the onset of containerisation in the 1960 s, but the more deliberate development of the rail shuttle system now called Railport Scandinavia started around 2000 as more and more shippers and hauliers showed interest in rail transport of containers. At this time, the rail monopoly was abolished and new rail operators entered the market, which contributed to increased competition in the market (Flodén and Woxenius, 2017). Entrepreneurs, such as local road hauliers also started to show interest in this segment and they understood the shippers' demands for timely, frequent and reliable services with a clear customer focus. The Railport system developed rapidly with more volume and more destinations up until the financial crisis in 2008/2009. Currently, the system has a market share of about 50% and more than 25 rail services with daily departures to and from the PoG (see Figure 2 for the volume development and Figure 3 for the current services and destinations).

Figure 2 Container volume development by rail in the Port of Gothenburg



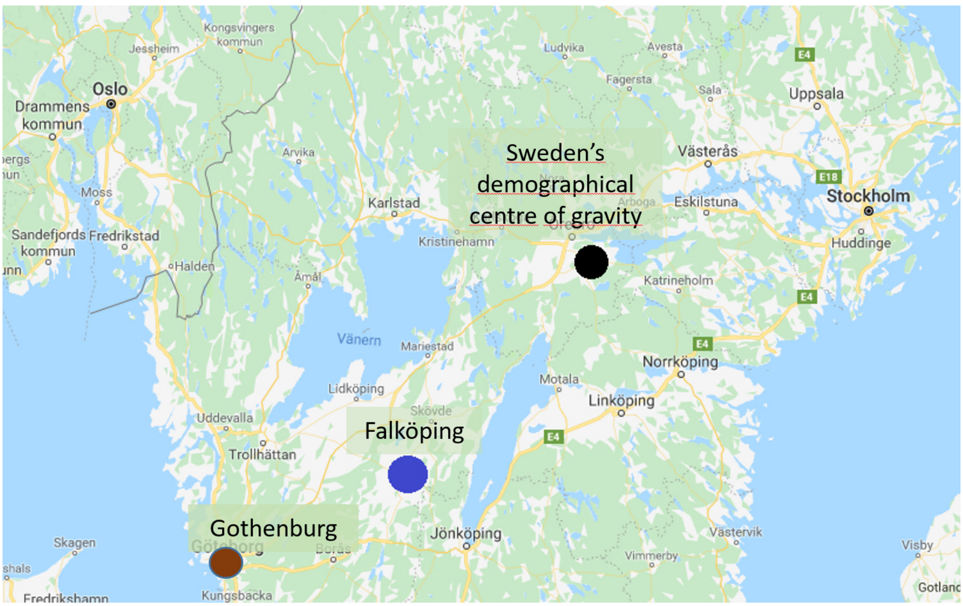
Source: Modified from Port of Gothenburg (2018a)

Figure 3 Railport Scandinavia: rail shuttles and destinations

Source: Port of Gothenburg (2018b)

Given the extended system of rail shuttles to and from PoG and the intermodal terminals, a number of interesting locations for DCs exist considering the Swedish and Scandinavian markets and the demographic centre of gravity of Sweden (SCB, 2019: highlighted as the black dot in Figure 4). For the purpose of our analysis, the terminal in Falköping, some 130 kms from PoG, will act as an illustrative example of a hinterland location.

Figure 4 Analysed locations of Gothenburg and Falköping, and also showing Sweden's demographic centre of gravity



Source: Adapted from Google Maps

Falköping is one of the biggest inland terminals in the Railport System with an annual turnover of about 25–30.000 TEU (Gonzalez-Aregall and Bergqvist, 2019). Since one of the biggest shippers using the rail shuttle to and from Port of Gothenburg is the import intensive company Jula AB, there is a big surplus of empty containers, making it a good opportunity to be used as a location for stuffing export containers. The main rail line between Stockholm and Gothenburg passes through Falköping, making it a good location for rail-based export goods like paper and pulp, enabling a match between export goods and large volumes of empty containers. Furthermore, Falköping is located fairly close to Sweden's demographical centre of gravity and taking into account that the majority of import of containers in Sweden enters via Port of Gothenburg makes it a good logistical location from a goods centre of gravity perspective.

In order to analyse and compare the two locations, a mix of qualitative analysis and quantitative modelling is used to assess the ton-km generated and related costs. The next section goes into detail on the model developed and the application of the model to the case study context.

4 Model description and assumptions

We present here a mathematical model that enables to identify the best location for operating a DC. Two options are compared. The first involves a DC located in the port surroundings according to port-centric logistics while the second involves a DC further away in the hinterland. The model analytically identifies the option that minimises total costs composed of inbound transport costs, processing costs at the DC and outbound transport costs. We derive some theorems that identify the best location depending of the value of the parameters involved. We keep the model tractable and therefore, an exact solution is identified. Additionally, we make use of the results to draw some insights on where to open maritime containers depending on the parameters' values.

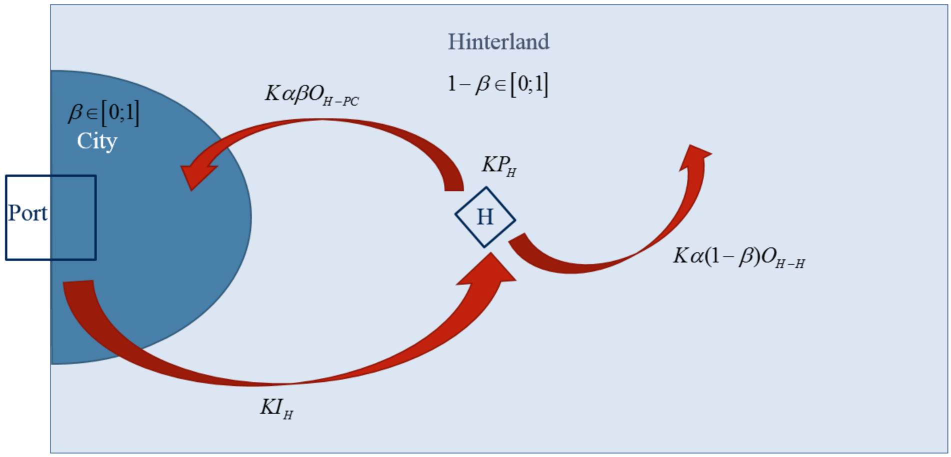
We focus on the hinterland of a large port city. We take a shipper's perspective and we focus on import flows. We assume that the shipper is serving both local demand in the port city and regional demand in the hinterland. We denote by $\beta \in [0;1]$ the ratio of local delivery. $\beta = 1$ implies that the shipper is operating only in the port city, while $\beta < 1$ implies that a share of the shipper's operations (i.e. $1-\beta$) is dedicated to regional delivery outside of the port city. The shipper is importing cargo via maritime transport, and we assume that the inbound flow to the shipper's DC is containerised. Maritime containers have standard dimensions, with the two most common types being 20 ft. and 40 ft. containers, of which the latter are used most. Therefore, we convert the inbound flow into Forty-foot Equivalent Units (FEUs). The annual inbound flow at the shipper equals K (expressed in FEUs/year).

We consider two options for the location of the DC: in the port city (based on the concept of port-centric logistics) or in the hinterland. We consider both exclusive options and non-exclusive options for the derivation of the analytical results. In the case of a DC located in the hinterland, we assume that the shipper locates it close to the centre of gravity of the demand to minimise outbound delivery costs, as the latter are often large compared to inbound delivery costs. This results from two factors. First, the inbound flow is containerised and, therefore, intermodal transport reduces costs via economies of scale. Second, the outbound flow has in general a much lower density compared to the inbound flow as is elaborated on in the introduction. Moreover, modern distribution logistics involves frequent small-size shipments. Let α be the number of outbound shipments generated per FEU (i.e. the total number of outbound shipments is αK). Based on the argument above, it is reasonable to assume that $\alpha > 1$. For instance, Monios et al. (2018), who focus on shipments to retail stores, assume that $\alpha = 6$.

We consider inbound costs, processing costs at the DC and outbound costs. These costs depend on where the DC is located. First, consider that the DC is located in the hinterland. We refer to Figure 5 for a visualisation of this setting. Let I_H be the inbound transport costs per FEU and P_H be the processing costs at the DC per FEU. Note that the subscript H is used throughout the article to denote the hinterland. Let O_{H-H} be the outbound transport cost per shipment for destinations in the hinterland and let O_{H-PC} be the outbound transport cost per shipment for destinations in the port city. If K FEU/year is passing through a DC located in the hinterland, the yearly logistics costs are calculated as follows:

$$Z_H = K\left[I_H + P_H + \alpha\left(\beta O_{H-PC} + (1-\beta)O_{H-H}\right)\right] \quad (1)$$

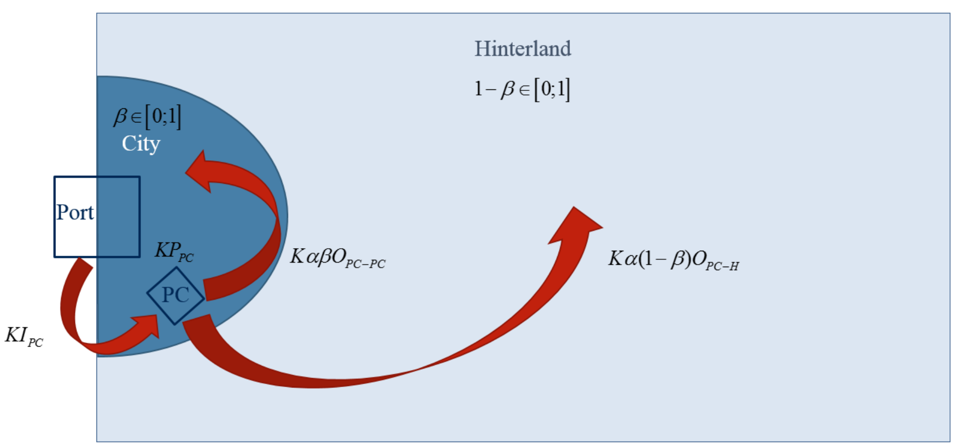
Figure 5 Yearly logistics costs when the DC is located in the hinterland



Second, consider now a DC located in the port city. We refer to Figure 6 for a visualisation of this setting. Let I_{PC} be the inbound transport costs per FEU and P_{PC} be the processing costs at the DC per FEU. Note that the subscript *PC* is used throughout the article to denote the port city. Let O_{PC-H} be the outbound transport cost per shipment for destinations in the hinterland and let O_{PC-PC} be the outbound transport cost per shipment for destinations within the port city. If *K* FEU/year is passing through a DC located in the port city, the yearly logistics costs are calculated as follows:

$$Z_{PC} = K\left[I_{PC} + P_{PC} + \alpha\left(\beta O_{PC-PC} + (1-\beta)O_{PC-H}\right)\right] \quad (2)$$

Figure 6 Yearly logistics costs when the DC is located in the port city



We can reasonably make the following assumptions. First, $I_H > I_{PC}$, as the DC is located much closer to the port in case of port-centric logistics. This is in line with Monios et al. (2018) who state that $I_H = €2360/FEU$ and $I_{PC} = €1000/FEU$ for the port city of

Gothenburg with several warehouses within a few kilometres from the port gates. Second, $P_H < P_{PC}$, as the labour costs, land costs and construction costs are higher in the port vicinity. In the same case study from Monios et al. (2018), $P_H = €26,546 / FEU$ and $P_{PC} = €29,934 / FEU$. Finally, we assume that $O_{H-PC} \geq O_{PC-PC}$ and that $O_{PC-H} \geq O_{H-H}$. Those are quite straightforward and mild assumptions.

5 Main results and general insights

In this section, we derive some analytical results highlighting the main features of our decision model. We consider first that a single DC is available, either in the port surroundings such as Port of Gothenburg or farther away in the hinterland, like Falköping. Then, we extend our results to the case for which two DCs are available, one in the port surroundings and a second one in the hinterland. Finally, we discuss the impact of taking economies of scale into account. Note that for each scenario, we derive some insights related to the ratio of port city versus hinterland deliveries, the ratio of outbound versus inbound shipments and the magnitude of inbound transport, processing and outbound transport costs.

5.1 Deciding on an exclusive distribution centre location

In this subsection, we aim at analysing the conditions that favour locating a DC in either the port city or the hinterland. We start by identifying sufficient and necessary conditions that favour locating the DC in the hinterland.

Theorem 1:

If $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H} = 0$:

$$Z_H < Z_{PC} \iff (I_H - I_{PC}) < (P_{PC} - P_H).$$

If $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H} > 0$:

$$\text{let } \beta^* = \frac{(P_{PC} - P_H) + \alpha(O_{PC-H} - O_{H-H}) - (I_H - I_{PC})}{\alpha(O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H})},$$

$$Z_H < Z_{PC} \iff \beta \in [0;1] \cap (-\infty; \beta^*).$$

The results of Theorem 1 reveal several patterns for deciding on where to locate container stripping activities. We focus first on the case for which $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H} = 0$, that is, $O_{H-PC} = O_{PC-PC}$ and $O_{PC-H} = O_{H-H}$. This holds when outbound transport costs are not impacted very much by the DC location and the destination of the cargo. Note first that this setting is in line with the assumptions from Monios et al. (2018) which are based on discussions with several decision-makers. In such a setting, the optimal location for container stripping activities is obviously independent of the share of regional versus port city deliveries (independent of β). The results we obtain in this case apply to Monios et al. (2018) and lead to the same conclusion. Monios et al. 2018 take $I_H - I_{PC} = 2360 - 1000$ and $P_{PC} - P_h =$

$29,934-26,546$. Theorem 1 highlights that in such a setting, $Z_H < Z_{PC}$. This is consistent with Monios et al. (2018). Note also that if inbound transport costs are negligible as compared to processing costs, $Z_H < Z_{PC}$ as $\left(I_H - I_{PC}\right) \approx 0$ => $\left(I_H - I_{PC}\right) < \left(P_{PC} - P_H\right)$, many shippers will still locate their DC in the hinterland (Heitz et al., 2020).

Our model enables us to go further in the analysis. First, as the size of the hinterland served by a port is increasing due to "terminalisation" (Rodrigue and Notteboom, 2009), DCs located in the hinterland are moving farther inland. Moreover, large port cities are becoming increasingly congested due to the concentration of the population and due to the rise of e-commerce (more pressure arises due to last-mile deliveries), also applicable in the case of city of Gothenburg. Second, some commodities, such as fresh products with a short shelf life and consumer products and spare parts with extremely tight lead times, show outbound logistics costs that are more sensitive to distance and congestion. In such cases, this becomes more likely as well to observe that $O_{H-PC} > O_{PC-PC}$ and $O_{PC-H} > O_{H-H}$. In this case, Theorem 1 identifies a key threshold in the ratio of regional versus local (port city) deliveries referred to as β^*.

The rest of the discussion in this subsection focuses therefore on settings for which $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H} > 0$. Note first that β^*, as stated in Theorem 1, is independent of *K*. This is because the decision model developed so far does not account for economies of scale. We discuss the impact of *K* in Subsection 5.3. Theorem 1 shows that a port city location for stripping activities is more likely to be beneficial for large β, that is, if the share of port city (local) shipments is large. Lemma 1 additionally enables us to identify some patterns along distribution channels.

Lemma 1: *Assume that* $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H} > 0$. *Then* β^* *is strictly decreasing in* α *if* $(P_{PC} - P_H) - (I_H - I_{PC}) > 0$.

Based on the arguments developed above, $\left(P_{PC} - P_H\right) - \left(I_H - I_{PC}\right) > 0$ in many cases. Therefore, we can apply Lemma 1 and conclude that β^* is likely to be decreasing in α. This means that port-centric locations for stripping activities are more likely to be developed for large α. Recall that α is the ratio of outbound versus inbound shipments. This means that α is likely to be large for e-commerce, for instance. This is a sign of potential business for port city-related stripping activities in large port cities handling an increasing share of e-commerce shipments.

As a final insight in this subsection, note that the increase in the size of the hinterland, the increase in congestion in port cities, and the increased sensitivities of cargo to outbound transport costs might lead to an increase in $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H}$. In case $\beta^* \in \left(0;1\right]$, the increase in $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H}$ leads to a decrease in β^*. This increases the likelihood of development for port-centric activities based on Theorem 1.

5.2 Delivering from the port and from the hinterland

In this subsection, we assume that two DCs are available. One of them is located in the port city and the second one is located in the hinterland. The results presented in this subsection are therefore special cases of the results obtained above. Note first that the results derived in the previous subsection are the background for the analysis of this new setting. Indeed, as economies of scale are absent from the decision model so far, splitting the inbound volume between two locations will not affect the analysis above. Note that we discuss what the impact will be of including setup costs for container stripping activities in a given location at the end of this section.

In the setting we consider in this subsection, the optimal strategy for deciding on where to open the container depends on the destination of the cargo inside the container. This requires "looking into the box". We can delineate two settings. At first, each container can contain a share of cargo for the port city and a share of cargo for the hinterland. Note that the results above can be directly applied to this new setting if we refer to the share of cargo for the port city as β.

Assume now that the cargo inside a given container is targeted solely for the hinterland. The total logistics costs if using the DC in the hinterland is:

$$Z_H = I_H + P_H + \alpha O_{H-H} \tag{3}$$

The total logistics costs if using the DC in the port city is:

$$Z_{PC} = I_{PC} + P_{PC} + \alpha O_{PC-H} \tag{4}$$

Theorem 2: *If the cargo is targeted solely for the hinterland, the optimal solution is to open the maritime container in the hinterland, if the following necessary and sufficient conditions are met*:

If $O_{PC-H} - O_{H-H} = 0$, $Z_H < Z_{PC}$ if and only if $\left(I_H - I_{PC}\right) - \left(P_{PC} - P_H\right) < 0$.

If $O_{PC-H} - O_{H-H} > 0$, let $\alpha^* = \dfrac{\left(I_H - I_{PC}\right) - \left(P_{PC} - P_H\right)}{O_{PC-H} - O_{H-H}}$. Then, $Z_H < Z_{PC}$ for all $\alpha > \alpha^*$.

Theorem 2 enables highlighting the following results in case the cargo inside maritime containers is targeted solely for the hinterland. First, if $O_{PC-H} - O_{H-H} = 0$, the optimal location depends on the sign of $\left(I_H - I_{PC}\right) - \left(P_{PC} - P_H\right)$. We mentioned in the previous subsection that this is quite likely that $\left(I_H - I_{PC}\right) - \left(P_{PC} - P_H\right) < 0$, which favours opening the container in the hinterland. Second, in case $O_{PC-H} - O_{H-H} > 0$, note that α^*, as defined in Theorem 2, might be negative. In such a case, $\alpha > \alpha^*$ and therefore, it would be less costly to open the maritime container in the hinterland. Third, Theorem 2 is in line with the principle that consists in loading cargo as early as possible in the transport chain and unloading it as close to the consignee as possible. Indeed, in the vast majority of cases, it is better to open a container targeted to the hinterland in the hinterland to benefit from cargo consolidation along the transport chain. Fourth, Theorem 2 additionally highlights specific settings that favour opening the maritime container in the port city. This applies when α is small $\left(\alpha < \alpha^*\right)$ and when $\left(I_H - I_{PC}\right) - \left(P_{PC} - P_H\right) > 0$.

Assume now that the cargo inside a given container is targeted solely for the port city (local shipment). The total logistics costs if using the DC in the hinterland is:

$$Z_H = I_H + P_H + \alpha O_{H-PC} \tag{5}$$

The total logistics costs if using the DC in the port city is:

$$Z_{PC} = I_{PC} + P_{PC} + \alpha O_{PC-PC} \tag{6}$$

Theorem 3: *If the cargo is targeted solely for the port city, the optimal solution is to open the maritime container in the port city, if the following necessary and sufficient conditions are met*:

If $O_{H-PC} - O_{PC-PC} = 0$, $Z_{PC} < Z_H$ if and only if $(P_{PC} - P_H) - (I_H - I_{PC}) < 0$.

If $O_{H-PC} - O_{PC-PC} > 0$, let $\alpha^* = \dfrac{(P_{PC} - P_H) - (I_H - I_{PC})}{O_{H-PC} - O_{PC-PC}}$. Then $Z_{PC} < Z_H$ for all $\alpha > \alpha^*$.

Theorem 3 enables emphasising the following results. We concluded in Section 4 that $P_H < P_{PC}$, as the labour costs, land costs and construction costs are higher in the port vicinity. If both inbound and outbound shipment costs are small relative to processing costs, the optimal location for opening the container is the hinterland, except if the number of outbound shipments becomes very high. This intuitive result is depicted very clearly in Theorem 3. This implies that a port-centric location is not necessarily the best option from an overall cost perspective for opening a container targeted for the port city. Overall, the results of Theorem 3 indicate that port-centric logistics should be dedicated to specific types of operations that require a large number of small outbound shipments to the port city.

5.3 Impact of economies of scale

This subsection is dedicated to an analysis of the impact of economies of scale. So far, our analysis has neglected economies of scale as the cost model does not include any volume effect. This is perfectly fine in some settings, for instance, when a shipper outsources transport and processing at the DC to external companies that do not propose any volume-dependent discount. However, from a general perspective, economies of scale are likely to occur.

Our model accounts for three type of costs, namely inbound shipment costs, processing costs at the DC and outbound shipment costs. First, we note that economies of scale are very difficult to create in practice for outbound deliveries. In case α is low, the unit load for outbound delivery is likely to be close to a full shipment and, therefore, economies of scale are not achievable as outbound shipments are generally made by road vehicles that are not very sensitive to volume above the level at which they are fully loaded. In case α is large, an outbound shipment will correspond to parcel delivery that is outsourced to LSPs in the majority of cases. From our knowledge, the rates proposed by those LSPs for parcel delivery are generally independent of the volume. Therefore, in the following, we discuss further the impact of economies of scale on processing activities at the DC and for inbound delivery.

Let us consider that economies of scale might be created for processing activities at the DC. This corresponds to a situation in which there is a setup cost for opening a new facility or some costs that are incurred independently of the volume handled. This will affect the result as follows. First, economies of scale in processing activities will naturally favour opening a single DC to direct as much volume as possible to this DC. This corresponds to the setting at the beginning of this section. Adding a fixed cost (independent of the volume) of operating the DC will affect the results as follows. First, the results of Theorem 1 highlight that only the difference in processing costs matters. Therefore, if the fixed costs are similar for a port city and for a hinterland location, those fixed costs will not affect our results. Second, if a difference in fixed costs exists, it is likely that the fixed costs are larger for a DC located in the port city as compared to a DC located in the hinterland. Therefore, accounting for economies of scale will not affect the results in case the hinterland location was chosen excluding economies of scale in processing activities. Moreover, in case a port-centric location was chosen without accounting for economies of scale, the advantages of this location will tend to be lower due to higher fixed costs for opening the facility. Therefore, the ratio of port city outbound shipments will need to be higher to ensure a viable port-centric location of the DC.

Consider now economies of scale for inbound transport. As we assume that inbound shipments are containerised, economies of scale can exist in case of intermodal transport. Intermodal transport for containerised cargo in the hinterland has drawn considerable attention as demonstrated in the introductory and case study sections. This literature and empirical data highlights that hinterland intermodal transport requires a minimal distance from the port to become effective and, therefore, most of the DCs located in port cities are served by trucks. Container trucking is not very favourable for building volume-dependent economies of scale and, therefore, we believe that economies of scale for inbound transport are more likely to affect DCs located in the hinterland. This would lead to the following behaviour. As *K* increases, I_H decreases due to economies of scale, so $I_H - I_{PC}$ decreases (but remains greater than 0), as I_{PC} does not depend on *K*. Based on Theorem 1, we can deduce that if $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H} = 0$, Z_H is more likely to be lower than Z_{PC}. Moreover, if $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H} > 0$, economies of scale for inbound transport leads to an increase in β^* that is in favour of a hinterland location for container stripping activities. Overall, the results show that economies of scale for inbound transport are likely to favour locating the DC in the hinterland. This shows a potential tension between the development of intermodal solutions in the hinterland and the development of port-centric activities, in line with recent research, such as that of Monios and Wilmsmeier (2012). The next subsection accounts for the model application to the case of Port of Gothenburg and the hinterland location of Falköping.

5.4 Port centric location compared with hinterland – case study results

For the purpose of the quantitative analysis, we assume that after the containers are stripped, the goods are transported to the nearest terminal of the area’s biggest LSP according to market share. After iterations of the share of outbound transport in the intracity region (< 130 km from city centre and port), we arrive at the following cost equilibrium where the share of intracity shipments must be more than 85% in order to favour a city-centric and port-centric location (see Table 1 for details of the comparison).

Note that the outbound shipments are palletised and the LSP's price tariffs are based on pallets; however, in reality, an outbound shipment consists of several pallets picked up at the same time. These are then delivered individually or in collections to different consignees as part of the LSP's general cargo or part load services.

Table 1 contains a detail account of the results of the model application (cost equilibrium) to the context of the case study where the port centric location at Port of Gothenburg is compares with the hinterland location of Falköping about 130 km from Port of Gothenburg.

Table 1 Cost equilibrium between a port-centric location in Gothenburg compared with a hinterland location in Falköping (in SEK, appr. = 0.0975€)

Cost component	*DC location*	
	Gothenburg	*Falköping*
Purchase of land		
Size of land, m^2	20 000	20 000
Price of land per m^2	x 800	x 55
Price of land	16 000 000	1 100 000
Land surveying and registry of property	30 000	30 000
Tax and expedition (4.25 % + 825 SEK)	+ 680 825	+ 7 575
Total cost of purchase of land	16 710 825	1 177 575
Municipality fees		
Surveying, planning and building permit	821 693	660 380
Connection fees, electricity, telecommunication, water and sewage	+ 1 028 142	+ 1 028 142
Total cost of municipality fees	1 849 835	1 688 522
Financing		
Purchase of land + municipality fees	18 560 660	1 319 880
Discount rate	x 5%	x 5%
Finance cost per year	**928 033**	**142 305**
Cost of construction		
Size of warehouse, m^2	10 000	10 000
Construction cost per m^2 incl. ground and land Work	x 6 500	x 6 000
Total construction cost	65 000 000	60 000 000
Residual value after 40 years of depreciation, % (Falköping has a lower residual value due to more peripheral location)	x 50%	x 40%
Residual value, SEK	32 500 000	24 000 000
Present value of residual value with 5% discount Rate	4 616 485	3 409 096
Construction cost – present value of residual value	68 383 515	56 590 904
Discount rate	x 5%	x 5%
Capital cost per year	**3 019 176**	**2 829 545**

Table 1 Cost equilibrium between a port-centric location in Gothenburg compared with a hinterland location in Falköping (in SEK, appr. = 0.0975€) (continued)

Cost component	*DC location*	
	Gothenburg	*Falköping*
Operating cost		
Heating per year and m^2 (70 SEK/y/m^2)	700 000	700 000
Insurance per year	300 000	300 000
Maintenance cost per year	+ 300 000	+ 300 000
Total operating cost per year	**1 300 000**	**1 300 000**
Cost of personnel		
Number of employees	20	20
Monthly wages per employee	x 27 000	x 25 000
Social fees, pension fees etc. (%)	+ 50%	+ 50%
Total cost of personnel per year	**9 720 000**	**9 000 000**
Inbound transport cost		
Number of incoming FEU	500	500
Cost of incoming FEU including post-haulage ($I_{PC} < I_H$)	x 1 000	x 2 360
Total cost inbound transport	**500 000**	**1 180 000**
Outbound transport cost		
Number of incoming FEU	500	500
Weight of goods per FEU, kg	x 20 000	x 20 000
Weight of inbound goods, kg	10 000 000	10 000 000
Weight of goods per pallet, kg	/ 500	/ 500
Number of outbound pallets	20 000	20 000
Transport cost per pallet ($O_{PC\text{-}H} = O_{H\text{-}PC} = O_{H\text{-}H}$)	300	300
Discount intra-port city due to short distance	- 20%	
Transport cost per intra-port city pallet ($O_{PC\text{-}PC}$)	240	
Share of intra-port city pallets	84.5%	
Total cost outbound transport	**4 985 641**	**6 000 0000**
Total yearly cost	**20 452 850**	**20 452 850**

Note that the operating costs P_H and P_{PC} are obtained by dividing the total operating costs (Finance cost per year + Capital cost per year + Total operating cost per year + Total cost of personnel per year) by the number of incoming FEU. We can notice that $P_H < P_{PC}$ for the case we focus on. From the analysis, we can clearly see that it would require a demand structure and distribution with a very high concentration going to the port city region (more than 85% of outbound shipments within a radius of 130 km) in order to favour a port-centric location. This analysis supports the notion that container stripping and freight distribution under normal circumstances is best situated outside city-centric ports. Our research illustrates that hinterland locations may serve as good alternatives for DCs, also when quite a large share of outbound shipments are destined for the port city and its vicinity.

6 Conclusions

This article addresses the topic of where to strip maritime containers containing import goods. It compares the options of opening the containers in warehouses in the vicinity of the port, further into the hinterland or a combination of the two. The article is divided into a literature review, developing a model with extensive analytical reasoning as well as a case study with a location study. The case study focuses import via Port of Gothenburg, Sweden, and illustrates the findings from the literature review and the modelling but also considering a wider set of decision parameters.

Outbound costs linearly related to distance give a favourable location close to the centre of gravity of demand (people/businesses). This favours inland locations close to the centre of gravity, which is most often located inland from the coast. Sweden is a peninsula and its most populated cities – Gothenburg, Malmö and Stockholm – are all port cities located on the west, south and east coasts respectively. This means that the demographic centre of gravity is placed in the middle of the comparatively well-populated south.

Dividing the inbound maritime flows between several ports, hence letting each port serve a more local hinterland, facilitates to shift the demographic centre of gravity so it favours port city locations if the outbound demand is concentrated near the port region. The urbanisation of port cities supports this trend in the long-term, but the change is occurring at a relative slow pace. However, by concentrating on value-adding production-related activities, the centre of gravity for demand might shift faster if the port supports relocation of such activities to the port-centric location. However, if the market consists of several port cities with growing demand where the total market supports a centralised inventory/warehouse location, this growth and concentration in port cities will offset the shift in gravity and thus support an inland location. Sweden and its market size is a good example of this. Demand consisting of small parcels or very large shipments, mainly full container loads, favours inland locations, but for some segments in between (larger parcels, general cargo and part loads) there might be favourable costs and lead times for the port-centric location.

The concentrated flows from the Port of Gothenburg to the hinterland facilitates economies of scale with rail shuttles leading to attractiveness of inland locations with intermodal opportunities for big shippers. The Port of Gothenburg should recognise this and focus its strategy by differentiating their port-centric logistics offer accordingly. It might lead small shippers to locate their warehousing closer to the port and large shippers to locate DCs in the hinterland closer to Sweden's demographic centre of gravity.

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Appendix A

Proof of Theorem 1:

$$Z_H - Z_{PC} =$$
$$K\left[I_H + P_H - I_{PC} - P_{PC} + \alpha\left(\beta\left(O_{H-PC} - O_{PC-PC}\right) + (1-\beta)\left(O_{H-H} - O_{PC-H}\right)\right)\right]$$
$$= K\left[\left(I_H - I_{PC}\right) - \left(P_{PC} - P_H\right) + \alpha\left(\beta\left(O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H}\right)\right.\right.$$
$$\left.\left.-\left(O_{PC-H} - O_{H-H}\right)\right)\right]$$

Note that $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H} \geq 0$ as $O_{H-PC} \geq O_{PC-PC}$ and $O_{PC-H} \geq O_{H-H}$. This enables us to delineate two cases:

Case 1) If $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H} = 0$, then $O_{H-PC} = O_{PC-PC}$ and $O_{PC-H} = O_{H-H}$. Therefore, $Z_H - Z_{PC} = K\left[\left(I_H - I_{PC}\right) - \left(P_{PC} - P_H\right)\right]$. We conclude that $Z_H < Z_{PC} <=> \left(I_H - I_{PC}\right) < \left(P_{PC} - P_H\right)$.

Case 2) If $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H} > 0$, then $Z_H - Z_{PC}$ is strictly increasing in β.

let $\beta^* = \dfrac{\left(P_{PC} - P_H\right) + \alpha\left(O_{PC-H} - O_{H-H}\right) - \left(I_H - I_{PC}\right)}{\alpha\left(O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H}\right)}$.

If $\beta^* < 0$, then $\left(P_{PC} - P_H\right) + \alpha\left(O_{PC-H} - O_{H-H}\right) - \left(I_H - I_{PC}\right) < 0$, so $Z_H - Z_{PC} > 0$ for $\beta = 0$. As $Z_H - Z_{PC}$ is strictly increasing in β, we conclude that $Z_H > Z_{PC}$ for all $\beta \in [0;1]$.

If $\beta^* > 1$, then $\left(I_H - I_{PC}\right) - \left(P_{PC} - P_H\right) + \alpha\left(O_{H-PC} - O_{PC-PC}\right) < 0$, so $Z_H - Z_{PC} < 0$ for $\beta = 1$. As $Z_H - Z_{PC}$ is strictly increasing in β, we conclude that $Z_H < Z_{PC}$ for all $\beta \in [0;1]$.

If $\beta^* \in [0;1]$, then $Z_H - Z_{PC} = 0$ for $\beta = \beta^*$. As $Z_H - Z_{PC}$ is strictly increasing in β, we conclude that $Z_H < Z_{PC}$ for all $\beta \in [0;1]$ such that $\beta < \beta^*$ (if any) 'We conclude that $Z_H < Z_{PC} <=> \beta \in [0;1] \cap \left(-\infty; \beta^*\right)$. This concludes the proof.

Proof of Lemma 1:

Assume that $O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H} > 0$.

Then, $\beta^* = \dfrac{\left(P_{PC} - P_H\right) + \alpha\left(O_{PC-H} - O_{H-H}\right) - \left(I_H - I_{PC}\right)}{\alpha\left(O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H}\right)}$

$= \frac{O_{PC-H} - O_{H-H}}{O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H}} + \frac{(P_{PC} - P_H) - (I_H - I_{PC})}{\alpha(O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H})}$. The first term is independent of α. $\frac{(P_{PC} - P_H) - (I_H - I_{PC})}{\alpha(O_{H-PC} + O_{PC-H} - O_{PC-PC} - O_{H-H})}$ is strictly decreasing in α if $(P_{PC} - P_H) - (I_H - I_{PC}) > 0$. This concludes the proof.

Proof of Theorem 2:

$Z_H - Z_{PC} = (I_H - I_{PC}) - (P_{PC} - P_H) + \alpha(O_{H-H} - O_{PC-H})$.

If $O_{PC-H} - O_{H-H} = 0$, $Z_H - Z_{PC} = (I_H - I_{PC}) - (P_{PC} - P_H)$ so $Z_H < Z_{PC}$ if and only if $(I_H - I_{PC}) - (P_{PC} - P_H) < 0$.

If $O_{PC-H} - O_{H-H} > 0$, $Z_H - Z_{PC}$ is strictly decreasing in α.

Set $\alpha^* = \frac{(I_H - I_{PC}) - (P_{PC} - P_H)}{O_{PC-H} - O_{H-H}}$. We can easily verify that $Z_H - Z_{PC} = 0$ when $\alpha = \alpha^*$. We conclude that $Z_H < Z_{PC}$ for all $\alpha > \alpha^*$. This concludes the proof.

Proof of Theorem 3:

$Z_{PC} - Z_H = (P_{PC} - P_H) - (I_H - I_{PC}) + \alpha(O_{PC-PC} - O_{H-PC})$.

If $O_{H-PC} - O_{PC-PC} = 0$, $Z_{PC} - Z_H = (P_{PC} - P_H) - (I_H - I_{PC})$ so $Z_{PC} < Z_H$ if and only if $(P_{PC} - P_H) - (I_H - I_{PC}) < 0$.

If $O_{H-PC} - O_{PC-PC} > 0$, $Z_{PC} - Z_H$ is strictly decreasing in α. Set $\alpha^* = \frac{(P_{PC} - P_H) - (I_H - I_{PC})}{O_{H-PC} - O_{PC-PC}}$. We can easily verify that $Z_{PC} - Z_H = 0$ when $\alpha = \alpha^*$. We conclude that $Z_{PC} < Z_H$ for all $\alpha > \alpha^*$. This concludes the proof.