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URBAN DISTRIBUTION CENTRES AND POLLUTION CHARGES: A SOLUTION FOR SUSTAINABLE URBAN LOGISTICS? THE EFFECT ON LOGISTICS PROVIDERS COMPETITION

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ABSTRACT

In recent years several European municipalities have paired market-based measures with urban distribution centres (UDC) in order to reduce CO2 emissions and make more sustainable urban freight flows, by improving the efficiency of the system. However, UDCs may add reloading costs and extra delivery times which have relevant impact on both urban supply chains and the competition among traditional and UDC-based logistics service providers in terms of service quality and freight rates. By using a duopolistic Hotelling framework, we show that market-based measures and subsidies might be substitutes to enhance the demand for UDC-based providers but public funding can be reduced by improving the quality of UDC services. These results can enlarge the scope for investments in UDC value-adding services in order to decrease private crowding-out effects in the long run.

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1. INTRODUCTION

Urban freight transport plays a crucial role in the sustainable development of many EU cities. In the last years, transportation and information advances, along with globalization, have dramatically expanded trades resulting in more dense urban city centres and crowded roads with goods distribution vehicles. Urban transport generates approximately 23% of overall CO2 emissions of which about a quarter is related to urban freight (OECD, 2014; Schoemaker et al., 2006). As about 80% of the EU population lives in urbanized areas, increasing negative effects of goods distribution turn out to be even more problematic into historical cities, especially in Italy, Spain and France (Erdmenger and Frey, 2010; Dablanc, 2007). Even though the volume of freight vehicles is estimated to be 10-20% of passenger traffic, most polluting freight vehicles largely contribute to negative side effects by producing 16 to 50% of the emissions of air pollutants. More, according to the *Air quality in Europe - 2016 Report*, despite in past fifteen years a persistent decline in the harmful emissions occurred, the amount of CO2 emissions was in 2014 around 40% higher than the official measurements (EEA, 2016). In economic terms, the adverse impact of road traffic in EU cities resulting in air pollution and gas emissions has been estimated to generate a damage roughly amounting to about 100 billion each year, corresponding to about 1% of the EU's GDP (MDS, 2012).

Beyond environmental issues, heavy and inefficient vehicles used to deliver goods in the urban areas also make city logistics itself further complex. In comparison to cost, timed-based factors and flexibility are central issues within modern delivery processes (EUROSTAT, 2011). With the future running towards urbanization, hence in European cities efficient urban freight distribution should coexist in hopefully less congested and polluted cities. As urban transportation in the EU faces a number of sustainable development challenges, the European Commission has set the objective of reaching free CO2 city logistics in major urban areas by 2030 (Lebeau et al., 2015). With the major aim to tackle the inefficient utilization of urban freight vehicles which does contribute significantly to environmental nuisances, several policymakers implement structural solutions together with market-based measured (i.e., congestion and/or pollution charges) (Maggi, 2007).

In the last twenty years, the most interesting and promising structural solution adopted by municipalities in order to rationalize urban freight flows has been the introduction of urban distribution centres (UDCs). These are logistics facilities usually situated in the proximity of a city centre where deliveries from logistics service providers are consolidated and distributed to urban customers (retailers, households) by using eco-friendly vehicles (Crainic et al., 2009; Browne et al., 2005). In principle, any Logistics Service Providers (LSPs) with deliveries scheduled for the urban areas can transfer their loads at UDCs and thereby avoid entering the congested sites. In turn, UDCs sort and consolidate loads from a number of LSPs and delivers them with electric/hybrid light vehicles to an agreed delivery pattern providing an opportunity to optimize consignment times and runs.

From the 2000s onward, 25 UDC projects in the UK, 14 in Germany, Italy and the Netherlands, and 11 in France have been undertaken. In France, the UK and the Netherlands about 33% of UDCs proceeded beyond feasibility studies, while in Germany and Italy about 40% of them were likely to be fully operational (Allen et al., 2012). Regardless the variable rate of success by country, however, the most crucial issue regarding the introduction of UDCs is the social acceptance of public subsidies often used to sustain their activities.

In times of post-crisis public funding cuts, without a clearly acknowledged acceptance of UDCs by a large number of stakeholders (including taxpayers), severe concerns about the financial viability of UDCs are at stake. The general view is that public subsidies sustaining UDCs are not necessarily a long-term policy solution, as they might undermine the incentive for UDCs' owners to invest in better equipment.

As shown in Table 1, in Italy a number of subsidized operational UDCs recently occur (Trentini et al., 2015). Main italian UDCs are linked to medium-sized cities (between 100,000 and 500,000 inhabitants) such as in Ferrara, Padua, Parma, Siena, and Vicenza, although other smaller cities (e.g., Frosinone and Aosta) have started to develop similar systems. At 2014, more than 15 UDCs was planned having important contributions from public authorities, either in the form of direct financing (e.g., Ferrara) or paired restrictive regulations to increase the attractiveness of UDCs (e.g., Modena, Parma, and Vicenza).

Table 1 - Recent UDC experiences in Italy (1999 – onward)

City	*Name*	*Type of subsidy*	*Starting year*
Siena	COTAS	Local	1999
Ferrara	Ecoporto	Regional	2002
Padua	Cityporto	Regional/Private	2004
Vicenza	VELOCE	Local	2005
Lucca	CEDM	EU	2007
Modena	Cityporto	Local	2007
Frosinone	C-Dispatch	EU	2007
Parma	ECOCITY	Local	2008
Venice-Mestre	-	Local/Regional	2008
Ravenna	CONSAR OBI	EU	2008
Abano Terme	Cityporto	Local	2009
Aosta	Cityporto	Local	2010

Source: Trentini et al. (2015), our elaboration.

In this paper we directly address the issue about how to limit public subsidies into UDCs by looking at many such funding-dependent logistics facilities which started to increase over time the proportion of cost recovered by customers, thus progressively reducing public contributions in the long run. In this way, the experience of the Cityporto in Padua is widely considered one of the most remarkable Italian successes. After four years of public subsidies (from 2004), local managers achieved a non-negative balance at the end of the fourth year (2008), when costs were covered by 75% of the total income without subsidies, and this target confirmed from 2009 onward (Morana and Gonzalez-Feliu, 2010). In practice, this goal has been achieved by signing up new users (i.e., larger market shares) and/or by providing quality improvements (value-adding services) to final customers, including stockholding, pre-retail activities, inventory control, reverse logistics (Aastrup et al., 2012).

In the light of the above consideration about value-adding services as potential way to reduce public subsidies associated with UDCs, however, two crucial issues may impede them to enhance these eco-friendly means of urban freight flows. First, despite many UDCs have shown social benefits ranging from reduced air pollution to improved road safety, their demand coming from LSPs is often unstable due to transaction costs typically associated to extra delivery times (route diversion, transshipment) and also UDC service costs (double marginalization). In a sense, we would investigate at what extent market-based policies (congestion and pollution charges) and public subsidies might offset those externalities which likely weaken UDCs' demand. Second, provided for value-adding services able to reduce the need for public subsidies in the long run, we enquire whether quality improvements can avoid final freight rate to increase at the detriment of customers. Indeed, since quality investments by UDCs are likely to raise freight transport demand, competition could be distorted and make end users prefer traditional providers anyway. In particolar, the present work tries to give a contribution on these issues, filling a literature gap. In fact, the impact of UDCs on the competition among LSPs already existing logistics providers has been devoted a rather scarce attention, but it is a crucial key for the effectiveness of the measure.

To deal with this issue, we develop a duopolistic Hotelling-based framework to study the effects of the introduction of public-private UDCs on LSPs spatial competition. In the model the customers (retailers) are located into city centres and are heterogeneous with respect to delivery times. According to many city logistics experiences in the EU, we consider that the choice of favourite LSPs by retailers is mainly based on freight rates and service quality, and that final delivery services are performed either by traditional or, in alternative, by UDC-based LSPs endowed with relatively less polluting (electric, hybrid) vehicles. In this setting, thus UDCs can be seen as intermediate (downstream) operators which are substitutes for LSPs (by contract) to perform last mile deliveries. Retailers have different preferences for horizontal time-related

characteristics of services (according to various supply chains) and also might be influenced by features (such as extra delivery times, market-based measures, public subsidies, and UDC quality investments) when choosing between traditional and UDC-based logistics providers to be patronized. To the best of our knowledge, this is the first theoretical paper attempting to model the impact of UDCs on the quality-price competition among LSPs by contributing to the two strands of literature reviewed below.

The paper is organized as follows. The next section provides an overview on the literature review and explicate the research questions. Then, section 3 presents the model, describing the two scenarios, pre- and post-UDC, while section 4 discusses the results, investigating the effects of semi-public UDC on LSPs competition. In particular, we focus our attention on the interplay between public subsidies and UDC quality investments to determine how the latter could trigger decreasing public subsidies and, at the same time, enhanced overall consumer welfare (i.e., on average, higher quality at lower freight rates). In the last section some conclusions and policy implications are drawn.

2. LITERATURE REVIEW

Our work first contributes to a conceptual and empirical literature related to the features influencing the potential demand for UDC-based services coming from LSPs (van Duin et al., 2010, Marcucci and Danielis, 2008). Voss et al. (2006) report that delivery reliability is critical to carrier selection, while delivery speed and final freight rates are also considered to be order winners according to Blackburn (2012) and Silveira (2005). Typically, the willingness to apply for UDC-based delivery services is high at the start of an initiative but the number of participating LSPs is usually not stable and lower than expected (20%), implying small economies of scale and reduced bundling possibilities (Regan and Golob, 2004). Marcucci and Danielis (2008) show that extra delivery times have a relevant statistical role in explaining the choice between UDCs and alternative traditional means of delivery. As these externalities depend largely on how UDCs are well-integrated in the urban context, their location outside the urban areas might have a pivotal importance. For example, whereas it is suggested that the UDCs should be located in central areas with high density of shops, it is also widely recognized that UDCs are unlikely to be attractive for many inner city retailers due to the degree of diversion required from normal routes. To conclude, the more acceptable solution is that UDCs should, if available, be close to modal nodes (highways, terminals) in order to minimize kilometres driven and reduce the route diversion entailing extra delivery times (Escuìn et al., 2012; Crainic et al., 2009; Browne et al., 2005). Different types of urban supply chain involved are also crucial characteristics in the urban freight transport competition. Following Danielis et al. (2013), retailers who sell perishable products which require daily- and-fixed consignments (e.g., fresh fruits and vegetables, milk and dairy products, bread and pastry, newspapers, etc.) are likely to be more time-sensitive because they compete with other similar retailers in terms of product selection with respect to those selling less perishable goods requiring weekly-and-flexible deliveries (e.g., meat, beverages, frozen food, clothing, stationary). Hence, more time-sensitive retailers are likely to demand for superior delivery services which UDCs should offer to related LSPs in terms of well-equipped facilities ensuring reliable and high-quality deliveries. In terms of policy interventions to sustain UDCs, accompanying command and control and market-based measures set up by municipalities can indirectly support these infrastructures, giving them competitive advantages, by imposing some restrictive measures to non-UDC vehicles. Beyond measures directly restricting goods delivery vehicles (i.e., time windows, LTZ) as in Vicenza (Ville et al., 2010), various market-based measures aim at internalizing common negative effects of urban deliveries (Maggi, 2007). For instance, pollution and congestion charges are introduced mainly to price the externalities caused (and commonly disregarded) by road users in city centres where urban delivery operations and traffic congestion are particularly critical. As widely observed, pollution charges imply that largely diesel-powered vehicles must pay a fee to enter in a certain area. Differently from congestion charges, they impose only the payment of fees, without forbidding circulation. The Ecopass system implemented in Milan (until 2012) entailed an integrated road pricing policy with free daily charges for low emission and/or electric geared commercial vans (Croci and Douvan, 2016).

The second strand of literature on which our work is based concerns the quality-price competition among firms in a Hotelling (1929) approach. As seen above, many features could combine together to affect the potential demand for UDC-based services. In our paper, following Hu et al. (2014) and Nagurney et al. (2014), we depart from the traditional literature on consumers' horizontal preferences, i.e., the distance between the most-preferred variety and the effective characteristic of goods (see among others, Anderson and De Palma, 1992) by assuming that the service feature which might differentiate LSPs is represented by delivery times. Hu et al. (2014) consider how lengthy could be the delivery of products to study the interaction between on-line and off-line distributions in the logistics competition. Whereas off-line competition implies transportation costs (customers have to travel to purchase goods), instead on-line competition entails penalty costs (customers receive goods delivered and thus are sensitive to consignment times). By contrast, Nagurney et al. (2014) develop a game theory model to analyze a supply chain network competition in time-sensitive markets in which consumers respond to the average delivery times associated with various products. In such both cases, however, the focus is on the impact of two or more kinds of costs on prices in a Hotelling framework, hence without considering any other variables affecting customers' demand.

Differently from these contributions, we enrich the spatial competition among LSPs by explicitly modelling time-sensitive customers (urban retailers) that are willing to pay a higher price either for more reliable (and faster) delivery times or, in alternative, whenever quality improvements (i.e., implied by value-adding services) may be provided by UDC-based LSPs. In this sense, regarding to the way in which quality is formally introduced in the Hotelling competition, the product differentiation literature has mainly allowed for quality as a strategic variable able to enhance customers' willingness to pay for goods and services. In terms of industry-specific variables, for instance, Allon and Federgruen (2007) analyze a market with service facilities competing on prices and lead time under varying types of competition. In this case, in a setting in which firms make their strategic decisions sequentially by selecting service levels and lead times, it is shown that the competition results in higher service levels, prices, and demand volumes. For the purpose of this research, however, our main reference is Economides (1989) who shows how (relatively cheap) quality investments may give firms the incentive to largely differentiate their products in the variety space (i.e., firms tend to become "insulated" to exert market power). This maximal differentiation suggests that higher quality (together with higher prices as well) have a two-fold effect on demand, that is, (i) local monopolies are more likely to occur and (ii) the full market coverage might be undermined by increasing market prices. In other words, firms might prefer to "cultivate" their captive customers by competing in quality rather than stealing them each others through a more fierce price competition. By contrast, Ma and Burgess (1993) enrich this result by showing that, however, quality might be also affect the price competition in an opposite direction. Since lower-quality firms have the incentive to reduce prices to retain their own demand, in a competition with strategic complements, average prices might turn out to decline.

In the light of the above controversial effect of quality on prices and by assuming time-based (horizontal) preferences in the urban logistics competition, our first aim is thus to answer the following question: before the introduction of UDCs, what is the effect of market-based measures (e.g., pollution charges) on the price-quality competition among LSPs? Do they increase freight rates and/or service quality? As we will describe later on, by this study we show that LSPs tend to pass-on market-based measures to urban retailers as they act as (common) costs. Furthermore, whenever retailers are more sensitive to delivery times (i.e., perishable goods, daily-fixed consignments), higher service quality come along with higher freight rates as well. In particular, market-based measures might thus stimulate LSPs to provide higher service quality in order to ensure a fully-covered market (i.e., own-account deliveries are neglected by retailers). But what about their effect on market shares? In a pre-UDC scenario, our model states that demands are not affected neither by preferences for types of deliveries nor by market-based measures. In other words, rather similar incumbents will internalize those features and split market shares proportionally. In the post-UDC scenario, however, other elements are at play. On the one hand, public subsidies are typically granted in order to make UDC-based services more attractive from the LSPs'´perspective (via reducing service costs). On the other hand (and with opposite effects), extra delivery times are likely to harm their potential demand. Thus, the second

main aim of our paper is to identify how market-based measures and public subsidies could combine to help UDCs limit their time-based negative externalities. In particular, we would also answer to the following questions. At what extent market-based measures and subsidies granted to UDCs might be substitutes or complements to increase the potential demand for UDC-based LSPs? And what about average freight rates? In this sense, we will show those policies might be substitutes to increase UDC-based LSPs' demand. As expected, whenever either charges or public subsidies are very high, retailers are more likely to patronize UDC-based LSPs. From a social point of view, since highly time-sensitive supply chains are the ones that are likely to generate much urban pollution and congestion, thus extra delivery times and UDC service costs will further weaken the potential demand for UDC-based services. In terms of post-UDC freight rates, as market-based measures and public subsidies instead are complements in order to lower average freight rates, thus higher charges would call for larger subsidies accordingly.

Finally, what could be here the role of UDC-based quality improvements? Our last result will put forward the idea for which enough high quality investments (in the form of value-adding services) might allow local governments to reduce subsidies with the result to convey, on average, higher service quality at lower freight rates in the post-UDC market.

3. THE MODEL

In order to include competition issues into the urban logistics market, we extend the standard Hotelling linear-city framework taking into consideration UDC service costs and extra delivery times as main negative externalities suffered from urban retailers patronizing UDC-based LSPs. Two scenarios will be contrasted. In the first (pre-UDC) scenario, identical LSPs providing delivery services to urban retailers are assumed to be subject to market-based measures (charges) to enter city centres. In the second (post-UDC) scenario, we consider the introduction of a public-private distribution centre located away from the city centre (i.e., with a certain level of diversion from normal routes) and assumed to use eco-friendly commercial vehicles (i.e., free of charges). From the demand side, in our general setting, urban retailers can choose between two LSPs, A and B, each offering one unit of delivery services. Following Hotelling's tradition, we assume that A is exogenously located at 0 on the X = [0; 1] axis, whilst B is located at 1, that is, at the opposite end point of the linear city. A mass of retailers (whose density is normalised to 1) is heterogeneous with respect to LSPs' delivery times, meaning that they are willing to pay a higher price for lower delivery times. In this sense, urban retailers' location between 0 and 1 describe time-sensitive retailers who prefer to patronize LSPs that are closer in term of time-distance. As a result, in this stylized duopolistic market, whenever both providers offer similar freight rates and service quality, retailers with a low (high) x would patronize LSP A (B) over B (A). Assuming that retailers' preferences are uniformly distributed along the city line, this framework also allows us to capture a key feature of the competition among LSPs, that is, the fact that delivery times might combine with freight rates in order to increase own market shares. Formally, urban retailers enjoy a net utility of $V_i(x)$ when patronizing one unit of delivery services from LSP i = (A; B), as follows:

$$
\begin{aligned}
&V_A(x) = bq - wx - f_A \\
&V_B(x) = bq - w(1-x) - f_B \qquad [1] \\
&(-\infty, 0)
\end{aligned}
$$

As shown in the above formulation, retailers are assumed to not be able to stock up goods as their shops size is constrained. This means that, for very high freight rates set by LSPs, they would consider outside options such as own-account deliveries. In other words, as retailers compete in downstream markets, it is assumed that the competitive quality-based loss they incur being served by LSPs is relatively bigger than the cost of own-account deliveries. More, following Economides (1989), we allow for a utility function that is separable in quality (vertical differentiation) and variety (horizontal differentiation). In addition to freight

rates, retailers' evaluation of a specific third-party LSP is assumed to be affected by two elements, i.e., their variable preference for delivery times and service quality.

As far as delivery times are concerned, we consider a parameter w > 0 that measures the cost of waiting for a unit of time. In a broader sense, this interpretation allows us to map different urban supply chains, ranging from less time-sensitive retailers requiring weakly-and-flexible consignments (lower w) to more time-sensitive retailers requiring daily-and-fixed consignments (higher w).

In terms of service quality, instead, the choice of a particular LSP by urban retailers is also assumed to be enhanced by the quality of delivery services offered. In this case, the level of service quality is seen as a "bundle" of different specific characteristics that improves customers' utility (i.e., relational attributes, full regulatory compliance, etc.). In our setting, LSPs rely upon service quality as a key variable to compete with rivals and, at the same time, to make retailers prefer to patronize third-party providers instead of recurring to own-account deliveries. In the pre-UDC scenario, in order to focus on the effect of freight rates on demand (markets shares), from now on we consider a symmetrical (exogenous) service quality q > 0 offered by each LSP. All else equal, this implies that, before an UDC is set up, retailers have the same gross willingness to pay for delivery services. The marginal utility of service quality is measured by the parameter b > 0.

From the supply side, we assume that operating costs (e.g., delivery logistics, vehicles maintenance, handling) can be accounted for each freight separately and set to zero. Fixed costs are nihil as they do not influence short-term freight rates. However, taking into consideration market-based measures established to reduce congestion or air pollution, in the pre-UDC setting we assume that A and B are traditional LSPs which perform consignments in inner urban areas using own (at some extent) polluting commercial vehicles. As a consequence, these vehicles entail marginal charges c > 0 set by municipalities. From a normative point of view, the parameter c can be interpreted as a proxy for the share of polluting commercial vehicles existing in an urban area. For instance, higher levels of c would mean that, on average, traditional LSPs make use of diesel-powered vehicles Euro 0, 1, 2, with PM10 emission factors from 50 to more than 100 mg/km.

3.1 Symmetrical pre-UDC scenario: equilibrium analysis

Before deriving the pre-UDC equilibrium, it is useful to define how LSPs' demand functions are influenced by freight rates and service quality. According to the utility functions described in (1) and given that the share of retailers patronizing A can be identified by its location 0 < x < 1, we derive A's demand as:

$$V_A(x) \geq V_B(x) \Leftrightarrow bq - wx - f_A \geq bq - w(1-x) - f_B$$

$$\Rightarrow x \leq x(f_A, f_B) = \frac{1}{2} + \frac{f_B - f_A}{2w} \equiv D_A(f_A, f_B) \qquad [2]$$

while B's (residual) demand is easily derived as:

$$D_B(f_A, f_B) \equiv 1 - D_A(f_A, f_B) = \frac{1}{2} + \frac{f_A - f_B}{2w} \qquad [3]$$

Retailers located close enough to zero (in terms of time-distance) in the X space are bounded by a threshold value of x above which they prefer to patronize A. In equilibrium, whenever LSPs offer similar levels of service quality and freight rates, the outcome in terms of market share implies the standard Hotelling result for which the market is split into two equal parts, that is, each LSP would gain half the market (as in Figure 2 below). For a given symmetrical service quality, thus LSPs must compete in freight rates in order to steal customers from rivals. To formally derive the equilibrium freight rates, we consider LSPs maximizing the following profit functions with respect to own freight rates:

$$\pi_A(f_A, f_B) = \int_0^{D_A(f_A, f_B)} (f_A - c)dx \qquad [4]$$

$$\pi_B(f_A, f_B) = \int_{D_A(f_A,f_B)}^{1} (f_B - c)dx \qquad [5]$$

By inserting [2]-[3] in [4]-[5] and applying the first order conditions to profits with respect to own freight rates, we derive LSPs' best response functions as follows:

$$f_A(f_B) = \frac{w + c + f_B}{2}$$
$$f_B(f_A) = \frac{w + c + f_A}{2} \qquad [6]$$

Equations in [6] clarify that freight rates are *strategic complements*, as the standard *50 cents-on-the-dollar* property applies. All else equal, an unilateral (marginal) freight rate increase leads to lower overall demand (i.e., the reaction functions shift up only by one-half) but also higher demand for rivals whose marginal revenues shrink, inducing them to raise freight rates as well (taking up the other half of the effect). By solving the above system we find pre-UDC freight rates and then by inserting [7] in [2]-[3] we obtain the related market shares in equilibrium as follows:

$$f_A = f_B \equiv f = w + c \qquad [7]$$

$$D_A = D_B = \frac{1}{2} \qquad [8]$$

From [7], as expected, we notice that LSPs are able to fully pass-on (common) charges to customers. More, for given identical service quality among LSPs in equilibrium, market power over captive customers (i.e., closer retailers on a time-distance basis) is enhanced by w. In terms of different urban supply chains, this result can be interpreted as follows. The more supply chains are time-sensitive, the larger is the market power that symmetrical LSPs might be able to exert on captive retailers.

The result in [8] for which equilibrium demands and prices are not affected by symmetrical service quality is rather standard in Hotelling static models. When quality is assumed identical among LSPs (and/or already set over a minimum standard level), it does not have any impact on market shares and, in turn, on freight rates. Should LSPs increase symmetrically their service quality (e.g., because they have roughly the same size and/or are endowed with similar IT equipments), own demands are left unchanged because the additional quality offered simply cancels out. In other words, identical quality across firms entails that demand neutrality does channel to price neutrality.

At this point, in order for a fully-covered market equilibrium to exist, we have to make sure that all the customers in the urban city centre would gain a (not strictly) positive utility being served by LSP A or B. In other words, it must be checked whether the "indifferent" customer (located at x = 1/2) would gain a utility greater than (or, at least, equal to) zero. This condition holds only if:

$$V_A\left(x = \frac{1}{2}, f = w + c\right) = bq - \frac{w}{2} - (w + c) \geq 0 \qquad [9]$$

that is, for a level of service quality (not strictly) greater than a (minimum) threshold denoted by $\bar{q}$:

$$q \geq \frac{1}{b}\left(\frac{3}{2}w + c\right) \equiv \bar{q} \qquad [10]$$

Valued at its sufficient level to ensure a fully-covered market (implying that even retailers located nearby the inner city centre would patronize one of the two LSPs), the symmetrical service quality provided in the pre-UDC scenario increases as retailers are more time-sensitive and/or with the extent of market-based

measures. Without loss of generality, hence we assume that in order to ensure a fully-covered market for urban freight transport (and thus deterring own-account deliveries), LSP A and B supply the minimum level of service quality $\bar{q}$. In terms of accompanying measures able to pair the effects of UDCs, here it is emphasized how charges set by municipalities affect the level of service quality. In our setting, the condition under which the urban freight transport market is fully covered ensures that, in principle, own-account deliveries are essentially ruled out by urban retailers. In particular, when local governments set increasing charges, at the same time, they induce LSPs to provide a rising level of service quality accordingly. As *obverse facet*, for a given level of charges, in case of more time-sensitive urban supply chains (higher w), hence market coverage is not ensured unless LSPs further increase own (minimum) service quality.

By summing up the results in [7] and [10], we state the:

Proposition 1. *(Pre-UDC equilibrium). Before the introduction of UDCs, in a fully-covered market:*

- *freight rates are neutral to symmetrical quality improvements;*
- *market shares are neither affected by market-based measures nor by retailers' time-sensitiveness;*
- *the extent of market-based measures (charges) is channelled to retailers in terms of both higher service quality and freight rates.*

A more general interpretation suggested by Proposition 1 is at point here. Before the introduction of UDCs into urban supply chains, market shares are equally spread among symmetrical logistics providers, regardless either the extent of market-based measures (pollution or congestion charges) or the heterogeneity of retailers' elasticity to delivery times. Intuitively, as in our setting retailers belonging to supply chains with daily-and-fixed consignment requirements are willing to pay more for reliable and faster deliveries, LSPs would indeed exert their market power accordingly on captive customers. In conclusion, in order to avoid polluting and less efficient modes of consignment (e.g., own-account deliveries), market-based measures set by municipalities are passed-through to customers in terms of higher freight rates and have the major welfare-oriented effect of increasing the (minimum) level of service quality provided by LSPs.

3.2 Asymmetric post-UDC scenario: equilibrium analysis

In this section our analysis departs from the previous (symmetrical) model of competition among LSPs to allow for the introduction of public-private UDCs in the urban freight transport market. Although an UDC may be potentially endowed with a monopolistic position in the last mile deliveries, we neglect such competitive distortion by focusing on unilateral incentives for a given LSP (say, B) to apply for UDC-based services. From a city logistics perspective, adding a downstream stage (reloading or transshipment node) to existing supply chains might influence retailers' choice conducing to an imperfect competition among LSPs in two ways. First, we refer to additional UDC service costs (including also handling, drafting, bargaining, etc.) which might reduce the efficiency of a certain supply chain by distorting (upward) freight rates. Second, whenever retailers are supplied by UDC-based LSPs, they might suffer from a disutility due to extra delivery times measured from UDC consignment to final deliveries. In general, as LSPs taking parcels to an UDC do not deliver goods to the customers, hence it is crucial to investigate what are the market conditions under which an LSP is willing to apply for UDC-based services to cover own last mile deliveries. In formal term, the utility function in [1] rewrites as follows (with a slight abuse of notation, we label post-UDC figures by using the superscript °):

$$
\begin{aligned}
&V_{A^\circ}(x) = bq - wx - f_{A^\circ} \\
&V_{B^\circ}(x) = b(q+\Delta q) - w(1+\alpha - x) - f_{B^\circ} \qquad [11] \\
&(-\infty, 0)
\end{aligned}
$$

where α ≤ 1/2 is a parameter which measures how time-consuming features associated to UDCs (i.e., transshipment and dwell times, inefficient location) might reduce the utility of retailers which patronize LSP B. The additional penalty for those customers crucially depends on either the distance of UDCs from highways (or easy-to-access modal nodes) or how well the UDC is integrated into the urban supply chain (i.e., degree of diversion required from normal route). Since UDCs are typically located barely outside city centres to minimize their distance to customers, here we assume that the related route diversion would imply an additional time-distance between UDCs and retailers (at most) equal to half the size of the city. This choice aims at avoiding unrealistic results for which UDC-based LSPs have zero market shares even by offering similar service quality and freight rates with respect to traditional LSPs. Put differently, overall freight rates and quality are still more crucial than location and/or route diversion in the market.

All else equal, as increases, the utility loss suffered by LSP B's customers becomes more severe. As regards the level of service quality offered after the introduction of UDCs, if it is kept identical among providers (as assumed in the previous scenario), therefore UDC-based LSPs would probably set higher freight rates (because of UDC service costs) and thus be less competitive than traditional rivals. In order to allow for quality improvements applied by UDCs, hence we assume that they can provide better (or value-adding) services (indicated by q > 0) with respect to traditional LSPs (still offering service quality $q = \bar{q}$, as in the pre-UDC scenario). In this way, we model a competitive environment in which LSPs would find UDC-based services advantageous only if the "cost" of last mile deliveries (in terms of revenue loss) is greater than UDC service costs. Clearly, this might hold unless UDCs are somehow able to provide value-adding services for which retailers are more willing to pay. Given the above modified utility functions, we derive the traditional LSP A's demand function as follows:

$$V_{A^\circ}(x) \geq V_{B^\circ}(x) \Leftrightarrow b\bar{q} - wx - f_{A^\circ} \geq b(\bar{q} + \Delta q) - w(1 + \alpha - x) - f_{B^\circ}$$

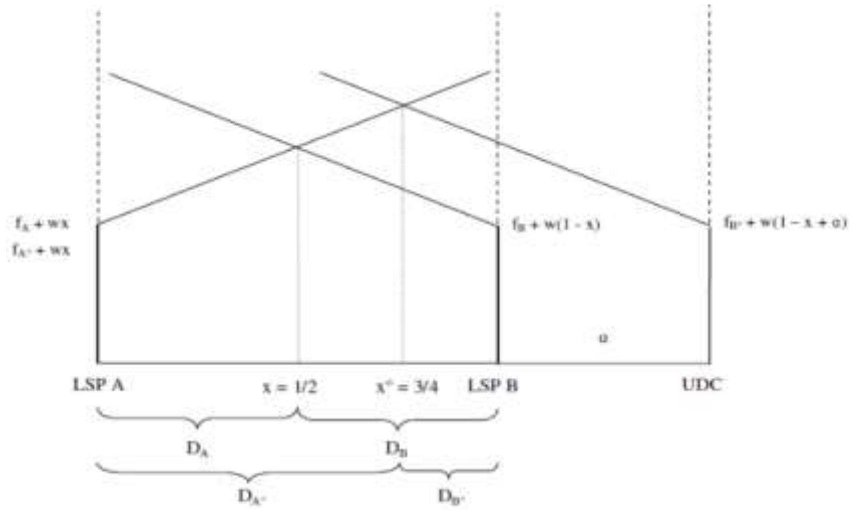
$$\Rightarrow x \leq x(f_{A^\circ}, f_{B^\circ}) = \frac{1+\alpha}{2} + \frac{f_{B^\circ} - f_{A^\circ} - b\Delta q}{2w} \equiv D_{A^\circ}(f_{A^\circ}, f_{B^\circ}) \qquad [12]$$

Still by focusing our attention on fully-covered markets, UDC-based LSP B's demand can be derived as a residual:

$$D_{B^\circ}(f_{A^\circ}, f_{B^\circ}) \equiv 1 - D_{A^\circ}(f_{A^\circ}, f_{B^\circ}) = \frac{1-\alpha}{2} + \frac{f_{A^\circ} - f_{B^\circ} + b\Delta q}{2w} \qquad [13]$$

Differently from the pre-UDC period, new features may affect LSPs' ´market shares. In particular, LSP B (A)'s potential demand is positively (negatively) affected by value-adding services (captured by the parameter Δq). Regarding to the negative impact of α on the demand for UDC-based LSPs, by inspecting [13], we observe that even by setting identical service quality (Δq = 0) and freight rates ($f_{A^\circ} = f_{B^\circ}$), LSP B might be not able to gain the leadership in terms of markets shares. As depicted in Figure 1, for symmetrical quality and freight rates, if extra delivery times turn out to be very large (α tends to 1/2), generalized costs associated to UDC services will amount to $f_{B^\circ} + w(1 - x + \alpha)$ for retailers patronizing B, while they will be still equal to $f_{A^\circ} + wx \equiv f_A + wx$ by choosing A. In this extreme case, the latter would gain about the 75% of the market (i.e., 3/4) while the former the residual 25% (i.e., 1/4). As a result, UDC-based LSPs cannot dominate over traditional ones (in terms of market shares) unless by lowering own freight rates and/or providing quality improvements.

Figure 1 – Pre and post-UDC market shares allocation (symmetrical case)



At this point, in order to derive the post-UDC equilibrium, the timing of the game is extended by considering LSPs competing in two stages. In the first stage, a public-private UDC establishes its service costs according to various level of public subsidies granted by municipalities. In the second stage, LSP A and B simultaneously set freight rates by taking into account their own demand functions. After the introduction of UDCs, our setting shifts from a symmetrical duopoly to an asymmetrical competition among traditional and UDC-based LSPs. In contrast to charges levied to traditional LSPs using polluting commercial vehicles, we suppose that UDCs perform last mile deliveries by using not-polluting vehicles. Basically, by applying for UDC-based services, LSP B might be able to avoid charges (i.e., c = 0).

In order to find the subgame perfect Nash equilibrium (SPNE) of the game in this post-UDC setting, we proceed by backward induction, starting from the second stage where LSPs maximize the following profits with respect to own freight rates:

$$\pi_{A^\circ}(f_{A^\circ}, f_{B^\circ}) = \int_0^{D_{A^\circ}(f_{A^\circ}, f_{B^\circ})} (f_{A^\circ} - c)dx \qquad [14]$$

$$\pi_{B^\circ}(f_{A^\circ}, f_{B^\circ}) = \int_{D_{A^\circ}(f_{A^\circ}, f_{B^\circ})}^{1} (f_{A^\circ} - s)dx \qquad [15]$$

where s > 0 represents endogenous UDC service costs. By substituting [12]-[13] in [14]-[15], the first order conditions yield the following best-response functions:

$$f_{A^\circ}(f_{B^\circ}) = \frac{c + (1+\alpha)w - b\Delta q + f_{B^\circ}}{2}$$
$$f_{B^\circ}(f_{A^\circ}) = \frac{s + (1-\alpha)w + b\Delta q + f_{A^\circ}}{2} \qquad [16]$$

Still in the post-UDC market, freight rates are strategic complements. Whereas increasing UDC service costs make B's response shift up inducing an increase in own freight rates, however, quality improvements crucially move A's reaction downward. In fact, whenever retailers benefit from value-adding services by patronizing LSP B, in the second stage, the lowest-quality LSP A would reduce its own freight rates to attract demand. Furthermore, increasing values of contribute to both the reaction functions as LSP B (A)'s

reaction would shift down (up). By solving the above system, we obtain the second stage equilibrium freight rates as functions of both UDC service costs and quality offered:

$$f_{A^{\circ}}(s) = \frac{(3+\alpha)w + 2c + s - b\Delta q}{3}$$
$$f_{B^{\circ}}(s) = \frac{(3-\alpha)w + c + 2s + b\Delta q}{3} \qquad [17]$$

From [17], both LSPs’´equilibrium freight rates increase with charges and UDC service costs (as they represent costs to be passed-on to customers). However, the extent of this effect is different among LSPs. While increasing charges affect A’s freight rates more effectively than B’s ones (i.e., 2/3 > 1/3), the opposite result occurs dealing with UDC service costs (i.e., 1/3 < 2/3). Here it is important to notice that two-thirds of UDC-based service quality are taken up in terms of increased B’s freight rates, while one-third of charges (levied to traditional LSPs only) still impacts on UDC-based LSPs. This means that, although municipalities set market-based measures to deter traditional deliveries, with competition in strategic complements, these charges does contribute to make UDC-based LSPs less competitive (by raising their freight rates).

Going backward we find the sub-game perfect equilibrium of the game by considering, in the first stage, the optimal choice of service costs level made by a public-private UDC. In this case, we consider a distribution facility which maximizes a weighted combination of profits and markets shares to model two key features of several welfare-oriented entities (such as schools, transport companies, hospitals, etc.). First, UDCs may need to make profits in competitive settings with decreasing public resources to spend, that is, facing not-that-soft budget constraints. Second, increasing market shares might be important to public-private UDCs because local governments aim at spreading out more eco-friendly ways to deliver goods in city centres. In other words, whenever UDCs contribute (at some extent) to maximize their vertical-related LSPs’ market shares, they also help inner cities to avoid more polluting commercial vehicles. As a consequence, the more UDCs are welfare-oriented (high public subsidies), the more they might be willing to enhance own service quality by (partially) disregarding the related effects on costs. Formally, we consider an UDC that maximizes the following objective function:

$$W(s) = \int_{D_{A^{\circ}}(f_{A^{\circ}}, f_{B^{\circ}})}^{1} (s + \theta - k\Delta q)\, dx \qquad [18]$$

where $\theta > 0$ is a parameter that measures the direct public subsidies granted to UDC operations. As θ increases, UDCs would take into account general public concerns (such as air quality and traffic congestion) and are willing to set lower service costs to induce more retailers to patronize LSP B. Marginal costs of quality investments are captured by the parameter $0 < k < b$. Two remarks are in order at this point. First, for a given level of quality improvements, UDC service costs must be sufficiently low to make LSP B set, in turn, lower freight rates and attract a larger demand. Second, as a welfare-oriented UDC is keen to lower its service costs, this fact potentially leaves smaller market shares (or residual demand) to traditional LSPs. To conclude the analysis of the first-stage equilibrium, we solve the UDC’s objective function maximization problem with respect to s (with related first order conditions):

$$s(\theta) = \frac{(3-\alpha)w + c - \theta + \Delta q(b+k)}{2} \qquad [19]$$

The interpretation of [19] reveals that, without public interventions (i.e., whenever $\theta = 0$), the only way for UDCs to lower own service costs is to reduce quality investments as well. Furthermore, in the presence of time-sensitive retailers (high w), the level of UDC service costs increases as well.

Finally, by inserting [19] in [12]-[17], we derive post-UDC freight rates and market shares (demands), respectively. The following formulations:

$$f_{A^{o}}(\theta;\Delta q)=\left(\frac{3}{2}+\frac{\alpha}{6}\right)w+\frac{5c-\theta-\Delta q(b-k)}{6} \qquad [20]$$

$$f_{B^{o}}(\theta;\Delta q)=\left(2-\frac{2\alpha}{3}\right)w+\frac{2c-\theta+\Delta q(2b+k)}{3} \qquad [21]$$

$$D_{A^{o}}(\theta;\Delta q)=\frac{9+\alpha}{12}-\frac{\Delta q(b-k)+c+\theta}{12w} \qquad [22]$$

$$D_{B^{o}}(\theta;\Delta q)=\frac{3-\alpha}{12}+\frac{\Delta q(b-k)+c+\theta}{12w} \qquad [23]$$

allow us to state:

Proposition 2. *(Post-UDC equilibrium freight rates). After the introduction of UDCs, traditional (UDC-based) LSPs' freight rates:*

- *increase with either market-based measures or in presence of more time-sensitive retailers;*
- *decrease with public subsidies;*
- *decrease (increase) with UDC quality improvements; and*
- *increase (decrease) with extra delivery times.*

As a result, in order to let UDC-based LSPs be more competitive, market-based measures and public subsidies must be complements.

As far as freight rates are concerned, Proposition 2 first shows that, similarly to the pre-UDC scenario, both retailers' elasticity to delivery times (captured by w) and market-based measures (measured by c) contribute to increase overall freight rates. In other words, after the introduction of UDCs, the above features still allow LSPs to exploit their market power over respective customers. However, in contrast to what concluded in Proposition 1, other aspects associated to UDCs might have an impact on equilibrium freight rates. Firstly, public subsidies will have a downward impact on both LSPs' freight rates, albeit with different magnitudes. Since freight rates are strategic complements, increasing public subsidies lower B's freight rates and channel this effect (at a smaller extent) to A's ones (i.e., 1/3 > 1/6). For the purpose of our research, by Proposition 2 we can conclude that, should UDC-based LSPs set the lowest freight rates, then higher charges have to be paired with large public subsidies as well. Secondly, the ability of UDCs to increase revenues by improving their service quality (e.g., value-adding services which would be channelled to LSP B's freight rates) might be crucially offset by extra delivery times generated by transhipment and route diversion. The reason behind this result is briefly explained as follows. Whereas quality improvements have a positive impact on customers' willingness to pay, instead extra delivery times act in the opposite way. Put differently, the highest-quality LSP B has the incentive to raise own freight rates accordingly but, at the same time, it must reduce them in order to cope with a potentially decreasing demand due to extra delivery times.

Turning to equilibrium markets shares occuring after the implementation of UDCs, their determinants are shown in the following:

Proposition 3. *(Post-UDC equilibrium market shares). After the introduction of UDCs, traditional (UDC-based) LSPs' market shares:*

- *increase (decrease) in presence of more time-sensitive retailers and extra delivery times;*
- *decrease (increase) with market-based measures, subsidies, and UDC quality improvements.*

In order to make UDC-based LSPs gain the largest market shares, market-based measures and public subsidies must be substitutes.

Differently from what concluded in the previous section, Proposition 3 shows that, in the post-UDC scenario, equilibrium market shares are strongly affected by features related to public policies. From UDC-based LSPs'´point of view, in particular we suggest that their market shares might be enhanced by three elements, i.e., UDC quality improvements, market-based measures, and public subsidies.

In the first case, *ceteris paribus*, quality improvements make retailers prefer to patronize LSPs which apply for UDC-based services. This implies that, by providing value-adding services, vertically-related LSPs might be able to cope with additional UDC service costs (double marginalization) and extra delivery times (captured by α). However, for given value-adding services, LSP A's captive customers may not switch to another logistics provider unless UDC is able to dramatically reduce extra delivery times (for instance, by limiting the diversion from normal routes and/or arranging UDC not far from highways or modal nodes).

As regards the interplay between market-based measures and public subsidies, Proposition 3 does stress their substitutability in order to let LSP B gain the leadership in terms of market shares. In particular, as done by market-based measures, also increasing public subsidies raise LSP B's market shares and reduce LSP A's ones. To conclude, in order to spread out less polluting deliveries in urban contexts (via larger UDC-based LSPs'´demand), more strict market-based measures (e.g., higher charges) would call for reducing public subsidies.

At this point, to derive the condition for a fully-covered market to be fulfilled, we must have that:

$$V_{A^{o}}(x = D_{A^{o}}(\theta;\Delta q), q = \bar{q}) \geq 0 \Rightarrow b\bar{q} - wD_{A^{o}}(\theta;\Delta q) - f_{A^{o}}(\theta;\Delta q) \geq 0 \qquad [24]$$

By substituting [20] and [22] in [24], in the post-UDC scenario all the retailers decide to patronize at least one of the two LSPs only if:

$$\theta \geq (3+\alpha)w - c - \Delta q(b-k) \equiv \theta^{o} \qquad [25]$$

An important result coming from [25] is at point. For whatever level of public subsidies beyond θ^{o}, two outcomes occur, that is, (i) the post-UDC market will be fully covered and, at the same time, (ii) UDC-based LSPs would gain the leadership in terms of market shares.

The intuition behind this conclusion is explained as follows. By setting public subsidies at their (at least) minimum level to ensure a full market coverage (i.e., $\theta \geq \theta^{o}$), we still have avoided some retailers not choosing any LSP and thus we have ruled out the preference for own-account deliveries. In turn, no empty sets of LSPs' customers in the post-UDC scenario also imply that freight rates (dragged downward by public subsidies equal to θ^{o}) are enough low to attract customers located in the middle of the city centre (that is, at x = 1/2). As a result, any (even slight) increase in terms of public subsidies would contribute to larger LSP B's market shares.

4. UDC QUALITY INVESTMENTS AND PUBLIC SUBSIDIES: A TRADE-OFF

In this last section we restrict our attention on the interplay between public subsidies and UDC quality improvements. More precisely, the role of value-adding services (i.e., pre-retail, stocking, tracing and tracking, return logistics, etc.) that could be provided by UDCs is analyzed to under stand at what extent this feature (combined to public subsidies) might influence the competition among LSPs in terms of freight rates. Since in our modelisation any quality improvements boost the willingness to pay of customers, indeed they are likely to enhance market power (and thus freight rates). As a consequence, in general, quality improvements offered by UDCs would entail that LSP B's freight rates will be greater than LSP A's ones. Anyway, recalling what concluded in the previous section, in a post-UDC fully-covered market, higher freight rates charged by UDC-based LSPs do not impede to gain larger market shares. In particular, whenever public subsidies are set above their minimum level to ensure the market coverage (i.e., $\theta \geq \theta^{o}$), UDC-based LSPs are able to gather the largest demand. From a normative perspective, the potential welfare-enhancing effect of UDC quality improvements might be unfortunately neglected by higher (average) freight rates. In fact, whereas some retailers will enjoy higher quality (via value-adding services) at higher freight rates by patronizing UDC-based LSPs, instead those still choosing traditional (not UDC-based) LSPs would pay less for having a lower quality. Although this result is not necessarily detrimental, it may be worthing to identify how many public subsidies are required to mitigate this alleged price-increasing effect of quality investments. More, in case of local governments aiming at gradually reducing the dependence of UDCs from subsidies (for budget reasons and/or to avoid crowding-out effects in the long run), thus we would like to investigate whether UDC quality improvements and decreasing public subsidies can be compatible with a post-UDC scenario in which, on average, retailers will enjoy a higher service quality at lower freight rates.

Before tackling this issue by considering post-UDC average freight rates, we must first derive the level of public subsidies for which LSP B's freight rates are likely to be lower than LSP A's ones. By comparing [20] and [21], we observe that, after the introduction of UDCs, LSP B may be (not strictly) more competitive than A when (arguments omitted):

$$f_{A^{o}} - f_{B^{o}} \equiv \frac{\theta + c - (3-5\alpha)w - \Delta q(5b+k)}{6} \geq 0$$

that is, for

$$\theta \geq (3-5\alpha)w - c + \Delta q(5b+k) \equiv \theta^{f} \qquad [26]$$

At this point, we may wonder whether any positive level of quality investments would increase UDC-based LSPs' freight rates, thus calling for larger public subsidies. Intuitively, since value-adding services increase the willingness to pay of UDC-based LSPs' customers, then quality features might enhance market power (and thus freight rates). As a consequence, in general, quality improvements would entail that LSP B's freight rates are expected to exceed LSP A's ones.

In this sense, by looking at [25] and [26], we find that the threshold θ^{f} is (not strictly) greater than θ^{o} when:

$$(3-5\alpha)w - c + \Delta q(5b+k) \leq (3+\alpha)w - c - \Delta q(b-k)$$

that is, only for a relatively high level of value-adding services, i.e., $\Delta q \geq \alpha w/b$.

In other words, for $\theta^{f} \geq \theta \geq \theta^{o}$, UDC-based LSPs are leaders in terms of market shares but their customers will likely be destined to pay more with respect to traditional LSPs' ones. In this case UDC quality improvements are completely channelled to LSP B's freight rates (i.e., $f_{B^{o}} \geq f_{A^{o}}$). By contrast, any level of public subsidies larger than θ^{f} would let UDC-based LSPs gain the largest market shares at the lowest freight rates (i.e., $f_{B^{o}} < f_{A^{o}}$). In other words, in a fully-covered post-UDC market, the relative extent

of UDC quality improvements does combine with public subsidies to determine whether UDC-based LSPs would be able to strive own market power over customers. The stronger the public effort in terms of subsidies, the higher is the ability of UDC-based LSPs to profitably operate in the market (i.e., larger revenues coming from value-adding services). In turn, this would imply that very high subsidies would also positively affect the potential demand for UDC services by LSPs.

Now, in order to compare pre- and post-UDC (not demand-weighted) average freight rates, we first define the latter as:

$$\overline{f} \equiv \frac{f_{A^o} + f_{B^o}}{2} \qquad [27]$$

then, by [7] and [27], we have that:

$$f - \overline{f} = \frac{\theta + c - (3-\alpha)w - \Delta q(b+k)}{4} \geq 0$$

only if:

$$\theta \geq (3-\alpha)w - c + \Delta q(b+k) \equiv \theta^{\overline{f}} \qquad [28]$$

In order to check whether, for $\Delta q \geq \alpha w / b$, the threshold $\theta^{\overline{f}}$ is effective in a fully-covered post-UDC market, we compare [25] and [28]. In particolar, since:

$$(3-\alpha)w - c + \Delta q(b+k) \geq (3+\alpha)w - c - \Delta q(b-k)$$

always holds for relatively high quality investments, we can conclude that both the thresholds θ^f and $\theta^{\overline{f}}$ are greater than θ^o for $\Delta q \geq \alpha w / b$. Turning to the comparison between [27] and [28], we also have that:

$$(3-5\alpha)w - c + \Delta q(5b+k) \geq (3-\alpha)w - c + \Delta q(b+k)$$

again for $\Delta q \geq \alpha w / b$. This means that, in the considered region, the ranking of thresholds related to public subsidies (in descending order) is the following: $\theta^f \geq \theta^{\overline{f}} (\geq \theta^o)$.

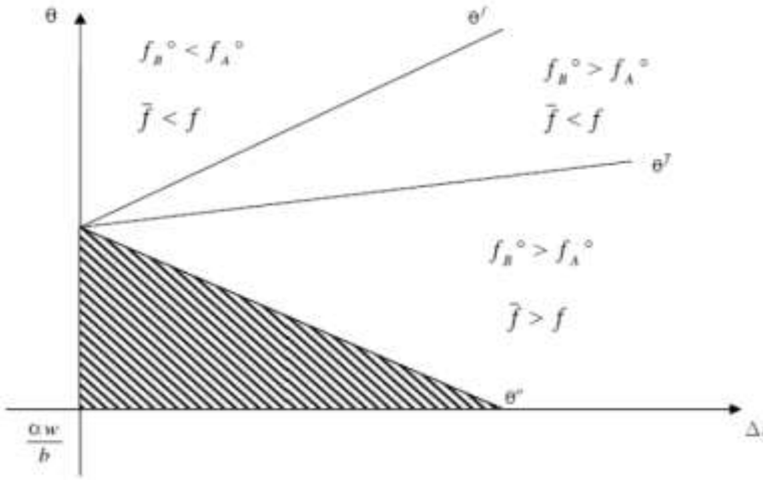
In summary, we can state the:

***Proposition 4**. (Trade-off between public subsidies and UDC quality investments). In a fully-covered post-UDC market:*

- *for relatively high UDC quality investments (with respect to retailers' elasticity to delivery times), decreasing public subsidies might be compatible with welfare-enhancing average freight rates in the market;*
- *the above required level of quality investments (i.e., value-adding services) is positively affected by both the type of retailers' supply chain (more or less time-sensitive) and the extent of extra delivery times associated with UDCs operations.*

As also described in Figure 2, Proposition 4 clarifies two main results related to the competitive interplay between UDC quality investments and public subsidies in the post-UDC scenario.

Figure 2 – Trade-off between public subsidies and UDC quality investments



Firstly, in presence of sufficiently high UDC quality improvements (proportional to how retailers' supply chains are time-sensitive), we enlist three relevant levels of public subsidies affecting competition in freight rates.

For relatively very high subsidies (i.e., $\theta > \theta^f \geq \theta^{\bar{f}} \geq \theta^o$), as expected, UDC-based LSPs can gain the largest available portion of market shares at the lowest freight rates. In a sense, they cannot exert a significant market power over captive customers and, as a result, average freight rates will shrink. From a consumer welfare perspective, this is probably the best outcome: higher service quality for almost the entire population of customers (retailers) in the market, paired with decreasing equilibrium freight rates. However, this might also imply very high costs in terms of public budgeting. In this case, local governments granting subsidies might not indeed commit to gradually reduce crowding-out effects (i.e., private investments are not incentivized). As a result, the dependence of UDCs upon public resources would remain high, with negative consequences on their social acceptance.

By contrast, for relatively very low subsidies (i.e., $\theta^f \geq \theta^{\bar{f}} > \theta \geq \theta^o$), UDC-based LSPs are still able to dominate the market even though at a smaller extent. In addition, they will set higher freight rates with respect to traditional LSPs (that is, by imposing a larger market power), inducing post-UDC average freight rates to rise up (i.e., $f_{B^o} > f_{A^o}$ and $\bar{f} > f$). In a sense, this situation might allow local governments to reduce the alleged dependence of UDCs upon public subsidies, but at a very high cost in terms of consumer welfare. In fact, now less urban retailers would benefit from higher UDC-based service quality and also, on average, consumers will be worse off (as post-UDC freight rates are higher).

However, as shown in Figure 2, there exists an intermediate region of public subsidies for which both private and public objectives might be satisfied. In particular, for a level of subsidies between $\theta^{\bar{f}}$ and θ^f, the following scebario will occur: (i) UDC-based LSPs can grab a significant portion of the market and also exert some market power over customers (still $f_{B^o} > f_{A^o}$), (ii) on average, consumers are better off as post-UDC equilibrium freight rates are lower than pre-UDC ones (i.e., $\bar{f} < f$), and (iii) local governments may be able to increase the social acceptance of UDCs as subsidies are not that high and also a rather large set of customers can benefit from a higher service quality by patronizing UDC-based LSPs.

The intuition behind this last result can be explained as follows. By recalling Proposition 2, whenever UDC quality investments are relatively high (increasing q), LSP B's freight rates could expand while LSP A's ones shrink, making the former exert a certain market power over own captive customers. However, as the impact of public subsidies on B's freight rates is more effective with respect to A, thus the minimum required level of θ in order to reduce average freight rates turns out to be lower. As a result, despite UDC-

based LSPs are less competitive than traditional rivals, overall customers are better off (i.e., a relatively larger number of retailers would benefit from higher quality at lower freight rates).

Secondly, the impact of the heterogeneity of urban supply chains (i.e., how retailers are time-sensitive in terms of delivery times) may be crucial in order to determine the extent of welfare-enhancing UDC quality investments. In fact, q has to be higher than an increasing function of w and α, respectively. All else being equal, the second result in Proposition 4 does stress out the fact that more time-sensitive retailers – along the discussion we have referred to supply chains characterized by daily-and-fixed consignments – would need higher UDC quality investments accordingly to boost vertically-related LSPs' demand (and market shares). In an analogous way, structural conditions affecting the extent of extra delivery times (e.g., UDC location and route diversion) are likely to influence (upward) the required level of UDC quality investments.

5. CONCLUDING REMARKS AND POLICY IMPLICATIONS

In this paper we use a spatial competition framework to study the effects of the introduction of UDCs on the competition among third-party logistics service providers. Our analysis has been conducted under two different scenarios. In the first (pre-UDC) scenario, as widely observed in many crowded and polluted cities around Europe, traditional LSPs perform parcels consignments to urban retailers into inner city centres by competing in service quality and freight rates but also facing market-based measures (i.e., congestion and/or pollution charges) set by municipalities to make the environment more sustainable. In the second (post-UDC) scenario, public-private UDCs are introduced into already established urban supply chains. In fact, by applying for UDC-based delivery services, vertically-related LSPs admit costs and benefits. On the one hand, extra delivery times (due to the fact that, for instance, UDCs may not be well-located outside urban areas and/or transhipments operations cause dwell times) and UDC service costs combine together to increase the total logistics costs of the supply chains. On the other hand, however, free-of-charge deliveries (typically, UDCs make use of eco-friendly electric commercial vehicles) and publicly subsidized UDC service costs may be able to reduce freight rates. In addition, UDCs might invest in service quality improvements (in the form of value-adding services) to reach a two-fold goal, that is, to increase their potential demand (coming from incumbent LSPs) and thus to be financially viable without relying upon subsidies in the long run.

By taking into consideration urban retailers that belong to variable time-sensitive supply chains, in this work we investigate the theoretical conditions under which LSPs might profitably apply for UDCs (i.e., to gather larger market shares) in a market in which service quality and freight rates are the main determinants of customers' choice. In this way, we obtain two main results.

First, by assuming that, in the fully-covered pre-UDC setting, service quality is symmetrical among LSPs (for instance, in case of incumbent integrators such as UPS, TNT or DHL having similar company size), we first show that either the extent at which retailers are time-sensitive or the level of market-based measures set by municipalities might have the major effect of making incumbent LSPs increase the (minimum) service quality offered. As a result, in the pre-UDC scenario, these features may allow LSPs to exert market power over exclusive urban retailers accordingly. For instance, in the presence of retailers belonging to more time-sensitive supply chains, LSPs might charge higher freight rates as their time-distance to captive retailers is smaller. Therefore, before the introduction of UDCs in the competition among LSPs, we can conclude that, for whatever type of supply chain involved, market-based measures effectively contribute to increase service quality to avoid more polluting forms of deliveries, i.e., own-account deliveries. Hence, this normative tool seems to be particularly suitable (and thus to be encouraged) in several historical cities (especially in Italy) where more polluting and less efficient deliveries are largely spread out, as shown by Danielis et al. (2012), for which in Italy the own-account figure accounts for 87% of overall domestic freight flows.

Second, after the introduction of public-private UDCs in urban supply chains, however, market-based measures might have a more subtle effect on the price-quality competition among logistics providers. On the one hand, they increase freight rates associated to traditional third-party consignments and thus give urban retailers the incentive to patronize UDC-based logistics service providers. In a sense, as widely recognized,

public intervention in the form of subsidies paired with sufficiently restrictive market-based measures can be crucial to stimulate eco-friendly urban freight flows. On the other hand, however, since logistics service providers compete in strategic complements (freight rates), those charges may contribute to make UDC-based logistics companies more expensive as well. Furthermore, if we take into account additional "costs" associated to UDCs, such as the double marginalization problem (i.e., downstream freight rates have to incorporate UDC service costs) and extra delivery times (e.g., UDCs are often not well-located outside urban areas), market-based measures imply two main controversial consequences.

In the first case, as congestion and/or pollution charges increase, the potential demand for UDC-based services may effectively be raised even in the presence of lower public subsidies. In particular, as charges negatively affect the demand of traditional LSPs, thus market-based measures and public subsidies can be considered as complements in order to boost the potential demand for UDC-based LSPs' deliveries. In this case, we refer to the V.E.L.O.C.E. distribution centre established in Vicenza (Italy) in 2005 where several municipal ordinances were applied (from April 2005 to December 2006), progressively reducing the traffic access to the local LTZ. Pairing these measures with a local UDC, the municipality was allowed to sustain the UDC's demand and thus facilitating its financial stand-alone viability.

In the second case, however, as market-based measures contribute to overall higher freight rates, they must be considered as substitutes to public subsidies in order to enhance the consumer welfare in terms of average post-UDC freight rates. At this point, by assuming that public-private UDCs may be able to make investments to improve own service quality (i.e., value-adding services), we obtained the last important result of our model. Whenever quality investments are enough large to cope with either more time-sensitive supply chains or extra delivery times induced by consolidation and/or route diversion, we show that a larger part of urban retailers would benefit from higher quality services (through UDCs) at lower average freight rates. From a public welfare point of view, hence quality improvements may substitute for public subsidies in order to reduce overall freight rates. In a sense, whenever UDCs invest in quality improvements, decreasing public subsidies can be sustainable in the long run and also UDCs might be viable as well. This last result seems to confirm recent experiences of successful UDCs where several value-adding services are provided and public subsidies have been gradually reduced, such as CityPorto in Padua. In particular, after 2009 (that is, the agreed expiration year for subsidies), in Cityporto tailored know-how was developed to answer logistics needs by proposing a wide variety of value-adding services including storage, management services, and assistance to national/international transports, focusing on rail-road intermodality.

Since the obtained results are encouraging, the future next step of the research will aim to empirically validate the model, by collecting data from at least two case studies of successful UDC implementation and building up structured interviews with LSPs, retailers, municipal delegates and other stakeholders involved in the projects. Thus, we will able to describe in details which are the business models applied the UDCs and their evolution in the last years of activity, as a reaction to public subsidies progressively decrease over time.

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