ON MEASURING THE EFFECT OF DEMAND UNCERTAINTY ON COSTS: AN APPLICATION TO PORT TERMINALS

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ON MEASURING THE EFFECT OF DEMAND UNCERTAINTY ON COSTS: AN APPLICATION TO PORT TERMINALS♦

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Abstract

A recent survey found that 40 per cent of the vessels arrive later than planned, so demand uncertainty is a salient feature of port terminal activity. Terminals facing greater demand uncertainty and who wish to cater for this will incur extra costs to avoid the risk that shipping companies replace them. We estimate a short-run cost function using data on three Spanish port terminals which includes demand uncertainty as a regressor. We find that demand uncertainty has a significant effect on costs and we quantify this. Not taking demand uncertainty into account may lead to port terminals' efficiency being underestimated.

Keywords: Demand uncertainty, port terminals, cost.

JEL Classification: L91, D24.

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1. Introduction

Although shipping companies assert that the majority of their lines work to a schedule with fixed days of arrival and departure which are programmed on a weekly basis, port terminals face uncertainty with regard to the arrival of ships. If terminals cannot satisfy demand and ships therefore have to queue for unacceptably long periods of time, the terminals face the risk that the shipping companies will replace the terminal with another with greater service capacity and lower queuing times.

Terminals thus have strong incentives to contract sufficient fixed and quasi-fixed inputs to minimize the probability that demand exceed service capacity, and to contract the variable factors necessary to handle unforeseen demand. This implies that terminals facing greater demand uncertainty may incur higher costs than those facing less uncertainty even though the total volume of cargo handled is the same.

This relationship between demand variability and firm costs is the focus of our study. In particular, we analyse how demand uncertainty and the desire of terminal managers to provide sufficient service capacity to meet this demand can affect costs of production. While this issue has been dealt with on a theoretical level for service firms by Duncan (1990) and in several applications to health-care providers (among others, Gaynor and Anderson, 1995; Carey, 1998; Baker et al., 2004), as far as we are aware no applications to transport service firms in general, and port terminals in particular, have been made in the literature to date.[1]

We attempt to fill this gap in the literature by studying the effects of demand variability on port terminal costs. We begin by discussing how demand variability may affect port costs and then present the theoretical framework which we use. In our empirical section, we use a panel

[1] Some research has, however, been done in on the risk attitudes of shipping company managers. See Lorange and Norman (1970) and Cullinane (1991).

data set of three Spanish port terminals covering the period 1991-1999 to estimate a short-run cost function which includes measures of demand uncertainty. Our results strongly support the hypothesis that demand uncertainty affects port terminal costs. An implication of our work is that analyses of port terminal performance based on cost functions which do not include indicators of demand uncertainty may provide a misleading picture and overestimate the inefficiency of terminals facing greater demand uncertainty. We illustrate this by showing how measures of cost efficiency may be affected when variables capturing demand uncertainty are not included in the cost function.

The paper proceeds as follows. In Section 2 we discuss how demand uncertainty affects port terminal costs and the implications of this when evaluating performance. The theoretical framework is presented in Section 3. In Section 4 we discuss the data set and the variables used. Section 5 contains the empirical specification of the cost function incorporating demand uncertainty and the results are presented and analysed in Section 6. Finally, Section 7 contains our conclusions and some possible extensions of our work.

2. Demand variability and port terminal costs

Recent technological innovations in maritime transport have increased the demand for port installations capable of dealing with new generation vessels and highlighted the importance of specialized port terminals (containers, bulk cargo, etc.), which have become an important factor when choosing a port. Terminals have displaced ports as the centre of competitive strategy and this has generated a notable increase in competition in the sector (Heaver, 1995). The terminals handling containers face an increasing flow of cargo which has to be dealt with as quickly as possible and at the lowest possible cost.

Shipping companies assert that the majority of their lines work to a schedule with fixed days of arrival and departure which are programmed on a weekly basis. Nonetheless, the demand which container terminals face is characterized by a degree of uncertainty. This is illustrated by a study carried out between April and September 2006 by Drewry Shipping Consultants (2006) that monitored the arrival of 5,410 ships on 23 trading routes and which found that over 40% of the ships arrived one or more days later than planned. Among the reasons for these delays are adverse weather conditions, delays at previous ports (due to, among other factors, congestion), breakdowns, etc.[2] In their study, Drewry Shipping Consultants (2006) state that most shipping companies do not make sufficient allowances for these contingencies when elaborating their schedules. Among the reasons for this behavior, they claim, is that shipping companies consider these margins or slacks to be too expensive.[3]

As a consequence, terminals face increasing uncertainty with regard to ships' estimated times of arrival, especially those who are not in the first port of call. A ship which arrives late affects planning at terminal docks and patios as it forces the terminal to deal with unforeseen volumes of cargo which may oblige it to contract additional factors of production (Vernimmen et al. 2007). In the worst case scenario, the ship may find the terminal occupied with other ships and thus have to queue. If this is a regular occurrence, the shipping company may reorganise the route and omit the terminal due to the high opportunity cost of having to wait.

Therefore, a port terminal which often finds itself unable to meet demand will experience delays in offloading cargo and this will affect the costs of the firms using their services.

[2] For example, the transit time for the route between the port of Santos (Brazil) and Port Elisabeth (South Africa) is affected by weather conditions in Cape Town which can cause delays of several days. See Notteboom (2006) for a detailed evaluation of the sources of delays.

[3] Notteboom (2006) identifies the costs associated with delays for the shipping firm and its clients. The shipping company faces additional operational costs derived from the ship being idle and the possible need to reorganize the fleet. Their clients face logistical costs derived from the increase in inventory costs and may even face operational costs if delays in the arrival of raw materials detain production.

These terminals therefore have a strong incentive to minimise delays in processing cargo, especially if alternative ports or other means of transport are available to firms moving goods because shipping companies ask for reliability with regard to delivery dates and promised handling times and have a stronger bargaining position than terminal operators (Wang and Cullinane, 2006). Consequently, terminal operators are forced to invest heavily to meet the stringent demands for faster service and higher reliability.

This desire to minimise delays and satisfy demand may influence the terminal's decisions when contracting fixed or quasi-fixed inputs, which in turn may affect the terminal's costs. Moreover, additional variable inputs such as personnel may have to be contracted on spot markets to cover unforeseen demand. This is important to take into account when evaluating the costs and, more generally, the production performance or efficiency of container terminals. In particular, terminals facing greater demand uncertainty may incur higher costs than those facing less uncertainty even though the total volume of cargo handled is the same. This will lead to situations where the high-uncertainty firm would be unfairly labelled as inefficient relative to the low-uncertainty firm if demand uncertainty were not taken into account.

The recent literature on port productivity has defended the idea of introducing additional productivity indices to the simply operational indices (Heaver, 2006; Bichou, 2007; Brooks, 2007; Talley 2007).[4] Bichou (2007) notes that efficiency and capacity utilization interact with quality and effectiveness. Ng (2006) assesses the attractiveness of ports in the North European Container transhipment market and includes port accessibility, time efficiency, cases of delay and costs as the most relevant criteria for users when making their choice of terminals. Tongzon and Ganesalingam (1994) suggest distinguishing two different set of efficiency

[4] See Oum et al. (1999) for a survey of efficiency and productivity studies in transport.

measures: operational efficiency and customer-oriented measures which includes reliability and vessels' waiting time.

What this literature highlights is that competitiveness may not be adequately captured by narrow definitions of efficiency, as competitiveness is a broader concept which implies providing a service with which the client is satisfied. Brooks and Pallis (2008) neatly summarize this with the following example: "*….[I]f a terminal operator improves its asset utilization by leaving more vessels at anchor so as to minimize downtime, its utilization is improved but the customer's service expectations may not have been met. In this case efficiency has come at the expense of effectiveness*". The corrolary of this is that port terminals that invest in additional service capacity (both in terms of fixed and variable factors of production) so that uncertain demand is catered for to the satisfaction of clients will be penalized in efficiency terms if this demand uncertainty is not taken into account.

3. Theoretical framework

The relationship between demand variability and firm costs has received quite a lot of attention in recent years in the economics literature, especially in health economics.[5] One of the ways in which it is argued that demand variability affects costs is that service firms will have quasi-fixed inputs on standby in order to minimise the probability that demand cannot be met by existing resources. These standby resources are costly and may often go unused, and firms facing higher demand variability will need to contract more quasi-fixed inputs than low variability firms (Duncan, 1990; Gaynor and Anderson, 1995). Demand variability may also affect costs by increasing the costs associated with purchasing inputs. Firm inputs such as

[5] See Lovell et al. (2009) for a recent study which contains references to this literature.

some types of labour and supplies may be purchased through long-term contracts or on shorter-term spot markets. Firms facing higher demand variability will find it harder to take advantage of long-term contracts than firms facing lower demand variability and if spot market prices are higher than prices through long-term contracts then costs will rise with demand variability (Baker *et al*, 2004).

The effect of demand variability on standby capacity was formalised in a theoretical paper by Duncan (1990) which was adapted by Gaynor and Anderson (1995) in a model of hospital costs which in turn gave rise to several papers in the field of health economics.[6] These models assume that firms make input decisions in two stages. In the first stage, firms choose fixed and quasi-fixed inputs which define service capacity subject to the contraint that the firm wishes to satisfy all but a small proportion of random demand. In the second stage, they choose variable inputs in order to meet the realized demand.

To see this in a little more detail, assume that the demand faced by a firm, in our case a port terminal, is a random variable, d, with conditional distribution function where d_{-1} represents past realizations of demand (or more generally, any information available to the firm which can be used to predict demand). The terminal chooses to have a service capacity, $\bar{d}$, which enables it to meet demand with probability β, which is termed the provision-of-service probability. That is, capacity $\bar{d}$ is chosen such that Now, if G is invertible, we can write $G^{-1}(\beta \mid d_{-1}) = \bar{d}$ and the terminal chooses fixed and quasi-fixed inputs to meet this maximum level of demand. As this maximum will exceed actual demand with probability β, terminals are effectively providing standby capacity which often goes unused and which will affect its costs. As Duncan (1990) notes, in effect, "… *what the firm incurs costs to produce is the*

[6] Indeed, the vast majority of research on the issue of demand variability and firm costs has been related to hospital costs in spite of the fact that Duncan (1990) explicitly recognised that the issue had applications in several fields, including transport.

option, the capacity, or the readiness to provide service at a certain level and only incidentally the observed output."

Cost analysis can easily be carried out in this framework by replacing output in a standard cost function C(y, w) by service capacity, yielding

$$C = C\left(G^{-1}\left(\beta \middle| d_{-1}\right), w\right) \tag{1}$$

This type of analysis is valid if inputs are fixed or quasi-fixed. However, if some inputs are variable in the sense that they can be freely adjusted to meet actual realized demand, then costs will also depend on the realization of demand and this should be included as an additional variable in the cost function (1). However, in order to empirically estimate a cost function of this kind, we still face the problem that we do not know the target service capacity which keeps the provision-of-service probability at or above its target level, β. However, if the distribution of demand is normal or approximately normal, then an increase in the variance of demand will increase target service capacity for a given provision-of-service probability. Gaynor and Anderson (1995) note that the mean and variance of demand conditional on past values can be used to describe desired service capacity for all provision-of-service probabilities. In particular, for a given provision-of service-probability, an increase in the standard deviation of the distribution, σ, will require a higher service capacity to maintain the same provision-of-service probability. Substituting $G^{-1}(\beta \mid d_{-1})$ with the standard deviation of demand and including realized demand as discussed above, a variable cost function which captures costly standby capacity can be expressed as

$$C = C(y, \sigma, w, k) \tag{2}$$

where y is actual output, w represents variable input prices and k is a vector of quasi-fixed factors.

Once fixed and quasi-fixed inputs have been chosen to provide target standby capacity, the firm must then choose its variable inputs. If variable inputs are freely (and, implicitly, costlessly) adjustable to meet actual demand, demand variability will not explicitly affect costs though purchases of variable inputs. Baker *et al* (2004) allow the possibility that demand variability affect costs at this second stage of decision-making through increasing input purchasing costs, an issue which has received less attention in the literature. The key issue here is that if it is costly to adjust inputs to meet actual demand then increased demand variability will affect firm costs. Of course, if variable inputs can be freely adjusted (that is, they can purchased on spot markets at the same price that is available through long-term contracts) then costs will not be affected by these adjustments. Terminals, for example, may have to pay overtime to personnel if ships arrive late. Also, terminals which have to contract temporary personnel to attend the expected arrival of a ship may find that the ship is delayed and they will have to pay the temporary workers regardless, in addition to the cost of attending the ship when it actually arrives.

To summarize, the literature above implies that costs may be affected by demand uncertainty for two broad reasons: (i) firms desire to have inputs on standby to provide a target provision of service and so they contract sufficient quasi-fixed inputs to ensure this target is met; (ii) firms wishing to meet a target provision of service will often have have to resort to more expensive spot markets to cover demand when it exceeds service capacity. We will be estimating a short-run cost function where the dependent variable is terminal operating expenditure. In line with discussion above, the inclusion of demand variables in such a function may be thought of as capturing adjustment costs associated with the contracting of quasi-fixed inputs prior to the realization of demand and the contracting of variable inputs after demand has been realized. The greater the variability of demand, the greater the need for prior standby capacity, and this may generate extra operating costs such as for example water, electricity, and maintenance costs. On the other hand, firms facing higher demand variability will need to adjust their variable inputs more frequently and any increases in costs associated with these adjustments will be captured by the demand variables in the cost function.

4. Data

The data we use have been gathered directly from three multi-user multipurpose port terminals operating in the Las Palmas Port Authority zone in the Canary Islands, Spain. [7] The fact that the three terminals under consideration are in the same port has the key advantage that the accounting data used are uniform and comparable. Moreover, the terminals face the same regulations and the remaining environmental factors are either equal or very similar for all of them.

The port of Las Palmas is an interesting case study for several reasons. Las Palmas is the fourth largest port within the Spanish system and the largest in the Mid-Atlantic Ocean in terms of container handling.[8] The three terminals in the port are private firms under concession and can be regarded as representative of medium size firms within the Spanish port system. Moreover, though there is no uniform pattern for port organization, there is an increasing worldwide trend towards the landlord model[9] (Juhel, 2001; Baird 2002). As the Spanish ports system follow this model and Spain's reform was similar to other port sector reforms worldwide (Tovar de la Fé et al, 2004), our terminals can be regarded as representative of medium size firms also within the world. Finally, there are some important

[7] See Jara-Díaz et al (2005) for more details.
[8] It is placed in the 81th position in the International Ranking of Container ports (Containerization International Yearbook, 2002)
[9] In the landlord model, the Port Authority leaves as many activities as possible in the hands of the private sector.

differences between the types of demand faced by the terminals analyzed, as we shall shortly see, and these will prove useful when analyzing the effects of demand uncertainty on costs.

We have monthly data covering the period 1991-1999.[10] The data run from 1992 to 1997 for Terminal 1, from 1991 to 1999 for Terminal 2 and from 1992 to 1998 for Terminal 3, yielding a final unbalanced panel data set of 264 observations. As we are estimating a short-run cost function, we need information on costs, outputs, input prices and the quasi-fixed inputs.[11] Our measure of short-run costs (C) is monthly total operating expenditure.

We distinguish between two outputs measured in total tons of cargo: Containers (Y_1), and Non-containers (Y_2). Table 1 shows the average percentage of total output corresponding to each category for both the full sample and for each terminal, from which it is clear that these terminals deal mainly with containers,

The evolution of the monthly movement of containers is illustrated in Figure 1, where it can be seen that Terminal 3 handles the greatest volume of container cargo and Terminal 2 the least. The figure shows a large increase in the volume handled by Terminal 3 from mid-1997 on: this was due to increased transit traffic attributable to the appearance of regular lines to northern Europe which use this terminal as a port of call.

The evolution of non-container cargo is quite different, as illustrated by Figure 2. Terminal 1 has the lowest volume of trafffic throughout the period, and Terminal 2 has the largest volume from September 1993 on.

Some descriptive statistics for the output data and the cost data are presented in Table 2 for the sample as a whole and for each terminal. The inputs used are labour, intermediate

[10] An advantage of our dataset is that we have access to very detail accounting information about the terminals' costs. This is important because as stated by Burns et al., (2006) "the most significant obstacle to effective benchmarking is the availability of good quality data on existing costs."
[11] See Tovar et al (2007) for a survey of production and cost function estimation in the port sector.

consumption and capital.[12] There are two broad categories of labour: non-port personnel and port personnel. Non-port personnel (LNP) includes, among others, administrative staff, executives and maintenance staff, whereas port personnel refers to stevedores or port workers, who handle cargo. The port personnel are in turn divided into two categories: those on the payroll (LP1) and those who are not (LP2). Those not on the payroll can be hired by the terminals on a provisional basis to work 6-hour shifts. The information available on labour is the number of staff per month for non-port personnel and the number of hours worked for port workers. The price of non-port personnel (w_{LNP}) is calculated as the average monthly labour expenditure per worker, while the price of port workers (w_{LP1} and w_{LNP2}) is total labour expenditure per hour worked.

Our quasi-fixed input is Capital (K), which consists of the monthly cost of the tangible assets of the company such as buildings and machinery. This cost has been calculated by adding the accounting depreciation for the period and the return on the active capital for the period which corresponds to the return on risk-free capital and which amounted to 8% per annum over the sample period.

All productive factors which are not included in the above categories, such as office supplies, water and electricity have been aggregated to form an input which we call Intermediate Consumption (IC). The price of electricity has been used as an indicator of the price of intermediate consumption (w_{IC}).

Closer inspection of the data in Table 2 reveals that in terms of average monthly variable expenditure Terminal 3 is still the largest. However, whereas Terminal 1 is larger than Terminal 2 in terms of total volume of cargo, in terms of total monthly expenditure their

[12] Information on port labour is very difficult to obtain. In previous papers dealing with port terminal efficiency, only Cullinane et al (2003) has such information.

ranking changes. The reason for this is the nature of the cargo they handle. Figures 3, 4 and 5 show the evolution of each category of output for each terminal and it can be seen that Terminal 2 is somewhat different from the others. In particular, the overwhelming majority of cargo handled in Terminals 1 and 3 is container cargo. Container cargo is also the main activity of Terminal 2 but it has a larger volume of non-container cargo than either of the other two, both in relative as well as absolute terms (recall from Table 1 that non-container traffic represents on average some 21.7 per cent of the monthly total tons handled for this terminal). As non-container cargo is more costly to handle, the fact that Terminal 2 is larger than Terminal 1 in terms of monthly expenditure but smaller in terms of total tons handled is explained by this difference in output mix.[13] .

We conclude this section with some comments on the variability of demand. According to the data in Table 2, there was an average total of 67,000 tons of cargo moved per month but the minimum and maximum values point to a large variation over the period studied. Indeed, the data show that the maximum reached five times the sample mean. Moreover, the degree of uncertainty faced by each terminal is different due to their characteristics. Whereas Terminals 1 and 3 are mainly involved in container traffic, they differ in that Terminal 1 primarily deals with ships from its own shipping company. Also, these ships fundamentally cover routes between Gran Canaria and the other Canary Islands and mainland Spain. Terminal 3, on the other hand, handles cargo from shipping companies which cover all kinds of routes, regional, national and international, and whose volume of transhipment has also increased substantially. Terminal 3 thus deals with ships whose probabilities of delay are much greater, and thus faces greater demand uncertainty than Terminal 1 as well as a greater danger of losing clients. Terminal 2 faces similar uncertainty to Terminal 1 in that the ships it deals with

[13] Basically, the grouping of merchandise into containers reduces labour needs and simplifies handling.

cover similar routes. Recall however that its costs will be higher because of its different product mix.

5. Empirical specification

Following the discussion above, to capture the effects of demand variability on costs we need an estimate of the mean and variance of demand conditional on past values to capture standby capacity for a given provision of service probability. Therefore, we need to estimate a demand forecast equation. The simplest form of the forecast equation is to relate present demand to the demand realized in the previous period. We thus model demand as a simple autoregressive (AR1) process. As demand is not directly observed, we use actual output as a proxy. The demand forecast equation to be estimated is specified as:

$$\text{Demand}_t = \alpha_i D_i + \alpha_t D_t + \alpha_d \text{Demand}_{t-1} + \varepsilon_t \qquad (3)$$

where D_i and D_t are port terminal and month dummy variables. To estimate the standard error of demand, we use the errors from equation (3) to estimate a variance function following Harvey (1976). Under this specification, Var(ε) = exp(zβ), where the z's are usually, though not necessarily, the same variables used in the mean (demand) function. We use the same variables, so we regress the log of the squared error from (3) on the firm and month dummies and the lag of demand. This permits us to estimate the standard error of demand, which will be our measure of demand uncertainty.

Table 3 shows the results from the demand forecast and demand variance. The forecast equation performs quite well, with an R^2 of 0.90 showing reasonably good predictive power.

While the variance equation does not have a particularly high R^2, an F-test soundly rejects the hypothesis that the slopes are jointly zero.

Our next step is to introduce the demand uncertainty variable into the short-run cost function and the parameter estimate will be used to test the hypothesis of whether demand uncertainty affects port terminal costs. We specify a translog functional form for the cost function, which provides a second-order approximation to any arbitrary function. Denoting our estimate of demand uncertainty as σ, for a model with *M* outputs, *J* inputs and quasi-fixed factor K the translog cost function and corresponding share equations can be expressed as:

$$\begin{aligned}\ln C \; &= \beta_0 + \beta_\sigma \ln\sigma + \sum_{m=1}^{M}\beta_m \ln y_m + \beta_K \ln K + \sum_{j=1}^{J}\beta_j \ln w_j \\ &+ \frac{1}{2}\sum_{m=1}^{M}\beta_{mm}(\ln y_m)^2 + \beta_{KK}(\ln K)^2 + \frac{1}{2}\sum_{j=1}^{J}\sum_{h=1}^{J}\beta_{jh}\ln w_j \ln w_h \\ &+ \sum_{m=1}^{M}\sum_{j=1}^{J}\beta_{mj}\ln y_m \ln w_j + \sum_{m=1}^{M}\beta_{mK}\ln y_m \ln K \\ &+ \sum_{j=1}^{n}\beta_{jK}\ln w_j \ln K + \sum_{t=2}^{T}\beta_t D_t \end{aligned} \tag{4}$$

$$S_j = \frac{\partial \ln C}{\partial \ln w_j} = \beta_j + \sum_{h=1}^{J}\beta_{jh}\ln w_h + \beta_{mj}\ln y_m + \beta_{jK}\ln K$$

where the usual restrictions of linear homogeneity in input and symmetry are imposed and D_t represents a set of annual time dummy variables.

The cost function and share equations will be jointly estimated using Zellner’s iterative SUR technique (ITSUR) where one of the share equations is dropped to avoid singularity of the variance-covariance matrix. As this estimation technique is equivalent to maximum likelihood estimation, the estimates are invariant to the share equation dropped and the parameters of the dropped equation can be recuperated from the restrictions imposed. To exploit the panel nature of the data we estimate the system (4) using a fixed effects estimator.[14]

The coefficient on the demand uncertainty variable allows us to test the hypothesis of whether adjustment costs due to demand variability are relevant to port terminal costs.

6. Discussion and Results

The fixed effects estimates of the cost and share equation system demand uncertainty are presented in Table 4. Homogeneity of degree 1 in input prices was imposed by dividing all prices by the price of intermediate consumption and all variables are expressed in terms of deviations from their mean values so that the first-order coefficients can be interpreted as cost elasticities at the means of the sample data.

Two sets of estimates are presented. The left hand side of Table 4 shows the results where the estimated value of the standard error of demand is used whereas the right hand side uses instrumental variable techniques, which we discuss below.

Focusing on the left hand side for the moment, we see that the ITSUR estimated cost function performs reasonably well in that most of the coefficients are significant and have the expected sign. In particular, the first-order input price coefficients are all positive and are all significant at conventional levels, and the first-order coefficient of the quasi-fixed input is negative and significant. Most importantly, the coefficient on the demand uncertainty variable is positive and highly significant, so the hypothesis that demand uncertainty has no effect on costs is soundly rejected.

[14] To be precise, we use the Least Square Dummy Variable technique, replacing the constant term in the cost equation with dummy variables for each of the three port terminals.

An issue which has not received attention in the empirical studies on the effect of demand uncertainty on costs cited above is that the variable capturing the uncertainty in demand has been estimated from a prior regression, giving rise to a potential error-in-variables problem which would make the demand variable endogenous and generate inconsistent estimates. To account for this possibility, we re-estimate the system (4) by instrumenting for the demand uncertainty variable. For instruments to be suitable, they must be uncorrelated with the dependent variable in period *t* yet be correlated with the potentially endogenous variables. As we have a panel data set, lagged values of the demand variables are potential candidates as instruments. As an instrument for the variability of demand, we propose using lagged differences in demand i.e. $\Delta y_{-1} = y_{t-1} - y_{t-2}$ as differences in demand from one period to the next should be positively correlated with demand variance.

While there is no reason to believe this instrument is correlated with present period costs, we should test whether the instrument is correlated with the endogenous variables, controlling for the remaining exogenous variables. To check this, we included the instrument as an explanatory variable in regressions of the estimated standard error of demand on all the exogenous variables in the system. If the coefficient on the instrument in these regressions is statistically significant then we can conclude that the instrument is correlated with the demand variables and we can consider it as acceptable. On the basis of the t-test, the hypothesis that the coefficient was equal to zero was rejected with a p-value of 0.021 so we conclude that the instrument is valid.

We therefore re-estimate the system using Three-Stage Least Squares (3SLS) and the results of this estimation are presented on the right-hand side of Table 4. As can be seen, the coefficients are quite similar to the previous estimation. In particular, the coefficient on the demand uncertainty variable is again positive and highly significant, reconfirming the hypothesis that demand uncertainty affects costs. The value of the coefficient is higher than it was before, which is consistent with the well-known fact that explanatory variables measured with error lead to attenuation bias, i.e., it causes a downward bias in the estimated coefficient.

Our results show that demand uncertainty affects port terminal costs, causing these firms to use more inputs than would be necessary in the absence of uncertainty. This implies that care should be taken when carrying out studies on firm performance and efficiency. For example, imagine two terminals with the same output as measured by tons of cargo handled but with different variabilities in demand. The terminal facing higher demand uncertainty will rationally use more inputs to satisfy potential demand, so as not to lose clients, than the terminal with the lower demand variability. If only actual observed demand and not demand uncertainty is accounted for, the high-demand terminal would be unfairly labelled as inefficient relative to the low demand firm as it would be judged to use more inputs to produce the same level of output.

To illustrate these issues, we calculated average cost efficiency indices for the sample period following the method proposed by Atkinson and Cornwell (1994) for translog cost functions with panel data. As output depends on demand and can thus be considered exogenous, we calculate input-oriented cost efficiency indices. Denoting the efficient input quantity as $x_i^* = b_i x_i$ and the input-oriented cost frontier, which represents the minimum cost of producing output y given input prices and technology, as $C^*(y, w_i)$, the observed cost of the firm can be expressed as $C_i = C^*(y_i, w_i)\cdot(1/b_i)$. Under a translog specification, $\ln(1/b_i)$ represents the distance of firm *i* from the cost frontier and provides a measure of input-oriented cost efficiency. For our panel data model, $\ln(1/b_i)$ is simply the fixed effect for each port terminal.[15] *b* is set to one for the most efficient firm and takes values less than one for inefficient firms. We estimate the inefficiency measures using three different cost frontiers based on three different estimations: an estimation of the cost frontier based on (4) with demand uncertainty excluded, and the two estimations reported in Table 4. The results are shown in Table 5 below.

We find that for all specifications of the cost frontier Terminal 1 is the most efficient followed by Terminal 2, with Terminal 3 being the least efficient. Accounting for demand uncertainty and estimating with Zellner's SUR estimator, the efficiency indexes are virtually identical. However, when the 3SLS estimator is used, the ranking is maintained but Terminal 3 appears much closer in efficiency terms to Terminal 2.

From our descriptive statistics we saw that Terminal 1 handled a much lower volume of non-container cargo than the other terminals. Given that this type of cargo is costlier to handle, it would be interesting to check how the other terminals' costs would be affected if they had the same volume of non-container cargo as Terminal 1. To check this, we can use the estimated coefficient on non-container output, β_{Y2}, to calculate what we label *Output mix-adjusted cost efficiency indexes* (OMCE). This index shows the reduction in costs for a terminal if they had the same non-container cargo as the terminal with the lowest volume of this cargo (Terminal 1 in our case). For the translog specification these can be calculated from the following formula:

$$\mathrm{OMCE}_i = \frac{\mathrm{Cost}_i\left(Y_{2i} = Y_{2MIN}\right)}{\mathrm{Cost}_i\left(Y_{2i} = Y_{2i}\right)} = \exp\left[\beta_{Y2}\left(\ln Y_{2MIN} - \ln Y_{2i}\right)\right] = \left(\frac{Y_{2MIN}}{Y_{2i}}\right)^{\beta_{Y2}} \qquad (5)$$

[15] Strictly speaking the individual fixed effect includes, apart from inefficiency, other sources of unobserved firm heterogeneity. Therefore, we need to assume that the unobserved firm heterogeneity not related to efficiency is constant across esimations.

from which it can be seen that where $OMCE_i = 1$ for the minimum non-container cargo terminal and $OMCE_i < 1$ represents the amount by which costs could be reduced for terminal *i* if it had the minimum non-container cargo.[16]

The calculations are presented in Table 6 for both the ITSUR and 3SLS estimates. As Terminal 1 has the lowest non-container volume, its index takes the value 1. Terminal 2 has the highest non-container volume and the values of the OMCE index show its costs could be reduced to 95 or 87 per cent of their present level depending on the estimation method used. This represents an additional cost to the terminal of between 19,000 and 51,000€ per month. As Terminal 3 has a similar volume of non-container cargo to that of Terminal 2 in absolute terms, its potential cost reductions are virtually the same.

More importantly, given the objectives of this paper, we can carry out a similar exercise in terms of demand variability. Terminal 3 has the highest demand variability of the three terminals and the fact that it has to incur higher costs to be able to meet its relatively more uncertain demand leads to its inefficiency being overestimated – these extra costs merely reflect the desire of the terminal to cover uncertain demand and the argument can be made that this should not be treated as inefficient expenditure. Terminal 1 had the lowest variance of the three, followed closely by Terminal 2 with Terminal 3 some way behind as we expected due to the terminal's routes and traffic (see section 4). As we did with the output mix, we can ask the question of how the other terminals' costs would be affected if they had the same variance as Terminal 1, all else being equal. Thus, we use the estimated coefficient of the demand uncertainty variable from the cost function, β_σ, to calculate *Variance-adjusted cost efficiency indexes* (CE_σ). As before, these can be calculated as:

[16] For example, $OMCE_i = 0.9$ implies that costs would be 90% of their actual value if Terminal *i* had the same non-container cargo as the minimum non-container cargo terminal (which is Terminal 1 in our case).

$$CE_{\sigma_i} = \frac{Cost_i(\sigma_i = \sigma_{MIN})}{Cost_i(\sigma_i = \sigma_i)} = \exp[\beta_\sigma(\ln \sigma_{MIN} - \ln \sigma_i)] = \left(\frac{\sigma_{MIN}}{\sigma_i}\right)^{\beta_\sigma} \qquad (6)$$

Again, $CE_\sigma = 1$ for the minimum variance firm and $CE_\sigma < 1$ represents the amount by which costs could be reduced if the firm had minimum variance. The calculations are presented in Table 7.

As Terminal 2 has a very similar demand variance to Terminal 1, its costs would not be affected much by a reduction of its variance to the level of Terminal 1. However, Terminal 3's costs would be significantly affected: if it had the same variance as Terminal 1, it's costs would be 97 per cent of those observed according to the ITSUR estimates and 85 per cent of observed costs according to the 3SLS estimates. These figures imply that Terminal 3 incurs additional costs of between 18,000€ and 89,000€ per month depending on the estimation method, compared to the minimum-variance terminal due to its efforts to cater for uncertain demand. Recall that in the presence of measurement error the ITSUR estimator causes a downward bias in the estimated coefficient, so the 3SLS estimate is higher. Again, these additional costs should not be considered as inefficiency, and if demand uncertainty is ignored we would be considerably overestimating Terminal 3's inefficiency. These results highlights the importance of the more general observation that we should be very careful when specifying cost functions when judging firm performance based on their estimation.

7. Conclusions

Port terminals face uncertainty with regard to the arrival of ships. If they cannot satisfy demand and ships therefore have to queue for unacceptable periods of time, the terminals face the risk that the shipping companies will replace the terminal with another with greater service capacity and lower queuing times. Terminals thus have strong incentives to contract sufficient inputs to provide a target provision of service probability which minimizes the probability that demand exceed service capacity.

This suggests that terminals facing greater demand uncertainty will face extra costs in order to meet the target provision of service probability. To investigate this possibility, using a panel data set of three Spanish port terminals over the period 1991-1999 we estimate a short-run cost function which includes a variable capturing demand uncertainty as a regressor. Our results confirm the hypothesis that demand uncertainty has a significant effect on costs.

We illustrate the consequences of this by estimating different cost inefficiency indices which permit us to quantify the additional costs generated demand uncertainty. We find that the terminal with the highest uncertainty has additional monthly costs of up to 89,000€ depending on the estimator used, or alternatively that its monthly costs could be reduced down to as far as 85 per cent of their current level if it faced the same demand uncertainty as the minimum-varaince terminal.

This leads us the conclusion that when analysing the costs of firms facing variable demand, as is the case of container terminals, researchers should test whether indicators of demand variability should be included. Failure to do so may lead to underestimation of terminal efficiency.

Finally, note that our research could be extended in several ways. We have adopted a dual, cost function appraoch to modelling the port terminals' technology but other approaches are also available, such as distance functions. Also, the efficiency itself could be modelled more explicitly using techniques such stochastic frontier analysis, which could permit demand uncertainty to be a determinant of efficiency. This may provide a fruitful line of future research.

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Table 1. Weight of each output category in total output (percentaje)

	Containers	Non-containers
Full Sample	87.4	12.6
Terminal 1	97.4	2.6
Terminal 2	78.3	21.7
Terminal 3	90.6	9.4

Table 2. Descriptive statistics of variables

	Variable	Units	Mean	Std Dev	Min.	Max.
Full sample						
Costs	Short-run costs (C)	Euro	446895	160987	267228	1356749
Output	Containers (Y_1)	1000 Tons	59.15	41.57	14.85	309.86
	Non-containers (Y_2)	1000 Tons	7.68	6.58	0.00	29.94
Input prices	Non-port personnel (w_{LNP})	Euro/month	2911	381	362	5563
	Payroll port workers (w_{LP1})	Euro/hour	66	19	16	174
	Other port workers (w_{LP2})	Euro/hour	56	6	39	89
	Intermediate consumption (w_{IC})	Euro/kwh	150	12	132	180
Fixed input	Capital (K)	Euro	78041	46452	30976	211851
Terminal 1						
Costs	Short-run costs (C)	Euro	363672	46614	267228	453235
Output	Containers (Y_1)	1000 Tons	53.12	9.72	32.21	73.99
	Non-containers (Y_2)	1000 Tons	1.54	1.04	0.03	4.07
Input prices	Non-port personnel (w_{LNP})	Euro/month	2921	417	2246	5563
	Payroll port workers (w_{LP1})	Euro/hour	65	17	156	119
	Other port workers (w_{LP2})	Euro/hour	57	9	47	89
	Intermediate consumption (w_{IC})	Euro/kwh	156	12	138	174
Fixed input	Capital (K)	Euro	36439	2584	30976	41602
Terminal 2						
Costs	Short-run costs (C)	Euro	388717	57511	283792	518343
Output	Containers (Y_1)	1000 Tons	33.46	7.45	14.85	61.64
	Containers (Y_2)	1000 Tons	10.67	7.52	0.00	29.94
Input prices	Non-port personnel (w_{LNP})	Euro/month	3041	292	2469	3685
	Payroll port workers (w_{LP1})	Euro/hour	58	9	37	86
	Other port workers (w_{LP2})	Euro/hour	55	6	39	78
	Intermediate consumption (w_{IC})	Euro/kwh	150	18	132	180
Fixed input	Capital (K)	Euro	66370	23680	33212	106499
Terminal 3						
Costs	Short-run costs (C)	Euro	593031	209699	394973	1356749
Output	Containers (Y_1)	1000 Tons	97.36	54.36	48.55	309.86
	Non-containers (Y_2)	1000 Tons	9.11	4.11	2.61	21.84
Input prices	Non-port personnel (w_{LNP})	Euro/month	2735	384	2165	3409
	Payroll port workers (w_{LP1})	Euro/hour	77	23	17	174
	Other port workers (w_{LP2})	Euro/hour	56	4	45	70
	Intermediate consumption (w_{IC})	Euro/kwh	150	12	138	174
Fixed input	Capital (K)	Euro	128713	42792	36818	211851

Table 3. Demand forecast and forecast variance equation estimates

	Demand forecast♠			*Demand variance*		
Variable	Coefficient	Std. Error	p-value	Coefficient	Std. Error	p-value
$Demand_{t-1}$	0.9857	0.0142	0.000	0.0201	0.0028	0.000
Terminal 1	102.42	50.59	0.043	1.7720	0.4547	0.000
Terminal 2	79.51	49.03	0.105	2.0255	0.3996	0.000
Terminal 3	90.98	48.07	0.058	1.7499	0.5475	0.002
Month 2	4.30	2.61	0.100	-0.7689	0.7646	0.316
Month 3	8.42	3.53	0.017	0.8909	0.4920	0.071
Month 4	2.48	4.10	0.545	0.3622	0.6550	0.581
Month 5	2.67	4.47	0.550	0.3732	0.5336	0.485
Month 6	6.21	4.68	0.184	0.9780	0.4639	0.036
Month 7	11.63	4.75	0.014	0.0484	0.5256	0.927
Month 8	1.29	4.70	0.784	-0.8467	0.6465	0.192
Month 9_9	2.34	4.51	0.604	-0.5699	0.5813	0.328
Month 10	7.90	4.17	0.058	0.0141	0.6096	0.982
Month 11	11.38	3.64	0.002	-0.1207	0.5779	0.835
Month 12	11.58	2.81	0.000	0.0741	0.5321	0.889
	$R^2 = 0.90$ F (zero slopes) = 129.0. (p = 0.000)			$R^2 = 0.17$ F test (zero slopes) = 3.47 (p = 0.000)		

♠ Demand is modelled as an AR(1) process.

*** p < 0.01
** p < 0.05
* p < 0.10

Table 4. Cost function parameter estimates

	ITSUR Estimates			3SLS Estimates		
Variable	*Coefficient*	*Std. Error*	*p-value*	*Coefficient*	*Std. Error*	*p-value*
$D_{Terminal\ 1}$	11.0010	0.0342	0.000	11.0353	0.0643	0.000
$D_{Terminal\ 2}$	11.1874	0.0250	0.000	11.1509	0.0502	0.000
$D_{Terminal\ 3}$	11.3657	0.0337	0.000	11.2179	0.0586	0.000
σ_Y	0.0357	0.0130	0.006	0.2055	0.0572	0.000
w_{LNP}	0.1390	0.0015	0.000	0.1393	0.0024	0.000
w_{LP1}	0.2392	0.0048	0.000	0.2405	0.0044	0.000
w_{LP2}	0.2893	0.0061	0.000	0.2876	0.0051	0.000
w_{IC}	0.3325	0.0029	0.000	0.3325	0.0037	0.000
K	-0.0703	0.0269	0.009	-0.0866	0.0376	0.021
Y_1	0.2746	0.0288	0.000	0.2523	0.0457	0.000
Y_2	0.0288	0.0084	0.001	0.0731	0.0126	0.000
$w_{LNP} \times w_{LNP}$	0.0330	0.0101	0.001	-0.0235	0.0166	0.156
$w_{LNP1} \times w_{LNP1}$	0.0772	0.0142	0.000	0.1116	0.0155	0.000
$w_{LNP2} \times w_{LNP2}$	0.0182	0.0272	0.504	0.0576	0.0326	0.077
$w_{IC} \times w_{IC}$	-0.0514	0.0313	0.101	-0.0250	0.0411	0.544
$K \times K$	0.1602	0.0903	0.076	-0.0044	0.1560	0.978
$Y_1 \times Y_1$	0.4137	0.0559	0.000	0.2866	0.1193	0.016
$Y_2 \times Y_2$	0.0006	0.0001	0.000	0.0019	0.0003	0.000
$w_{LNP} \times w_{LP1}$	-0.0218	0.0031	0.000	-0.0244	0.0086	0.005
$w_{LNP} \times w_{LP2}$	-0.0479	0.0089	0.000	0.0009	0.0161	0.955
$w_{LNP} \times w_{IC}$	0.0367	0.0128	0.004	0.0470	0.0207	0.023
$w_{LNP} \times K$	0.0368	0.0035	0.000	0.0352	0.0050	0.000
$w_{LNP} \times Y_1$	-0.0075	0.0036	0.040	-0.0136	0.0059	0.021
$w_{LNP} \times Y_2$	-0.0011	0.0008	0.175	-0.0005	0.0007	0.430
$w_{LP1} \times w_{LP2}$	-0.0202	0.0174	0.246	-0.0618	0.0174	0.000
$w_{LP1} \times w_{IC}$	-0.0352	0.0146	0.016	-0.0253	0.0142	0.076
$w_{LP1} \times K$	0.0467	0.0108	0.000	0.0482	0.0091	0.000
$w_{LP1} \times Y_1$	-0.0453	0.0109	0.000	-0.0507	0.0105	0.000
$w_{LP1} \times Y_2$	-0.0057	0.0035	0.106	-0.0055	0.0012	0.000
$w_{LP2} \times w_{IC}$	0.0499	0.0233	0.032	0.0033	0.0292	0.910
$w_{LP2} \times K$	-0.0601	0.0128	0.000	-0.0617	0.0107	0.000
$w_{LP2} \times Y_1$	0.0158	0.0155	0.308	0.0255	0.0125	0.041
$w_{LP2} \times Y_2$	0.0087	0.0049	0.074	0.0080	0.0014	0.000
$w_{IC} \times K$	-0.0234	0.0066	0.000	-0.0218	0.0079	0.006
$w_{IC} \times Y_1$	0.0370	0.0079	0.000	0.0388	0.0092	0.000
$w_{IC} \times Y_2$	-0.0019	0.0007	0.003	-0.0019	0.0010	0.057
$K \times Y_1$	-0.1723	0.0433	0.000	-0.2108	0.0711	0.003
$K \times Y_2$	0.0015	0.0098	0.876	0.0185	0.0197	0.349
$Y_1 \times Y_2$	-0.0009	0.0057	0.869	0.0328	0.0169	0.053
D_{1992}	0.0489	0.0250	0.051	0.0288	0.0516	0.576
D_{1993}	-0.0402	0.0258	0.119	0.0132	0.0503	0.794
D_{1994}	-0.1009	0.0258	0.000	-0.0268	0.0509	0.598
D_{1995}	-0.1359	0.0296	0.000	-0.0671	0.0549	0.222

Cont.:						
D_{1996}	-0.1082	0.0300	0.000	-0.0057	0.0538	0.916
D_{1997}	-0.1478	0.0317	0.000	-0.0472	0.0532	0.376
D_{1998}	-0.0701	0.0355	0.048	0.0477	0.0595	0.423
D_{1999}	-0.0890	0.0354	0.012	0.0968	0.0630	0.124
R^2 Cost function:		0.76			0.89	
No. observations: 258						
Heteroskedasticity-robust estimates						

Table 5. Input-oriented cost efficiency indices from alternative cost systems

	Input-oriented Cost Inefficiency Indices		
	Cost system without demand uncertainty	Cost system with demand uncertainty	
		ITSUR	3SLS
Terminal 1	1.000	1.000	1.000
Terminal 2	0.826	0.830	0.891
Terminal 3	0.688	0.694	0.833

Table 6. Output mix-adjusted cost efficiency indices from alternative cost systems

	Output mix-adjusted Cost Inefficiency Indices	
	ITSUR	3SLS
Terminal 1	1.000	1.000
Terminal 2	0.948	0.868
Terminal 3	0.950	0.878

Table 7. Variance-adjusted cost efficiency indices from alternative cost systems

	Variance-adjusted Cost Inefficiency Indices	
	ITSUR	3SLS
Terminal 1	1.000	1.000
Terminal 2	0.998	0.988
Terminal 3	0.972	0.851

Figure 1. Monthly movement of containers ('000 tons)

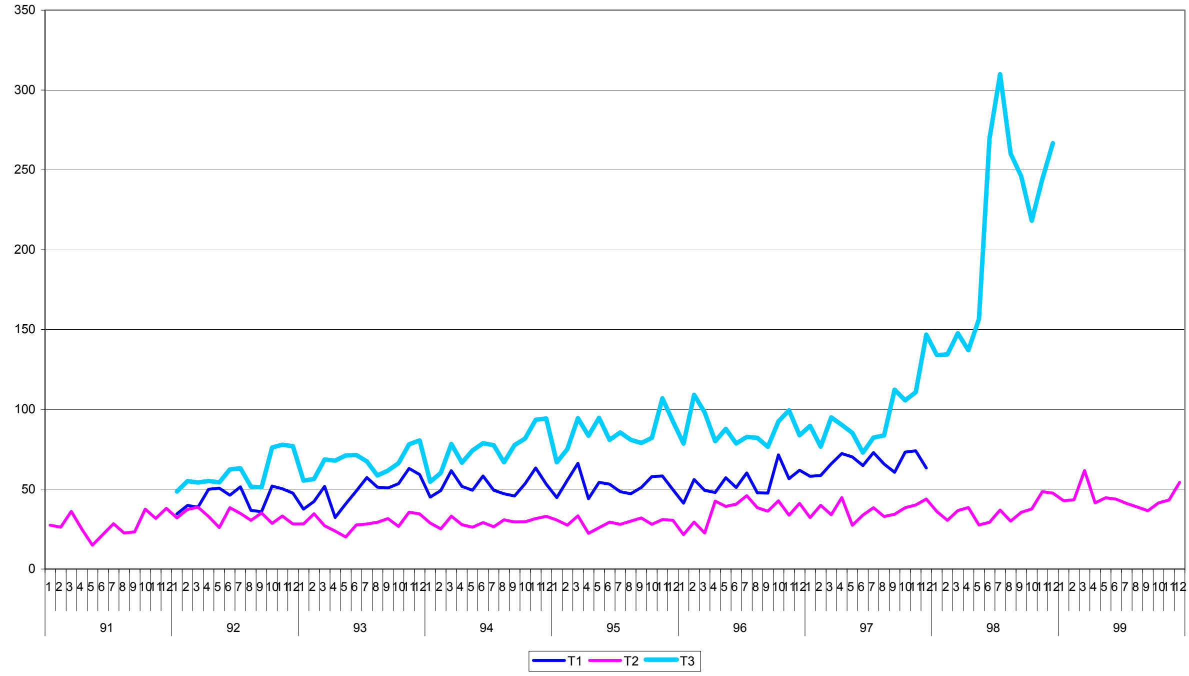


Figure 2. Monthly movement of non-containers ('000 tons)

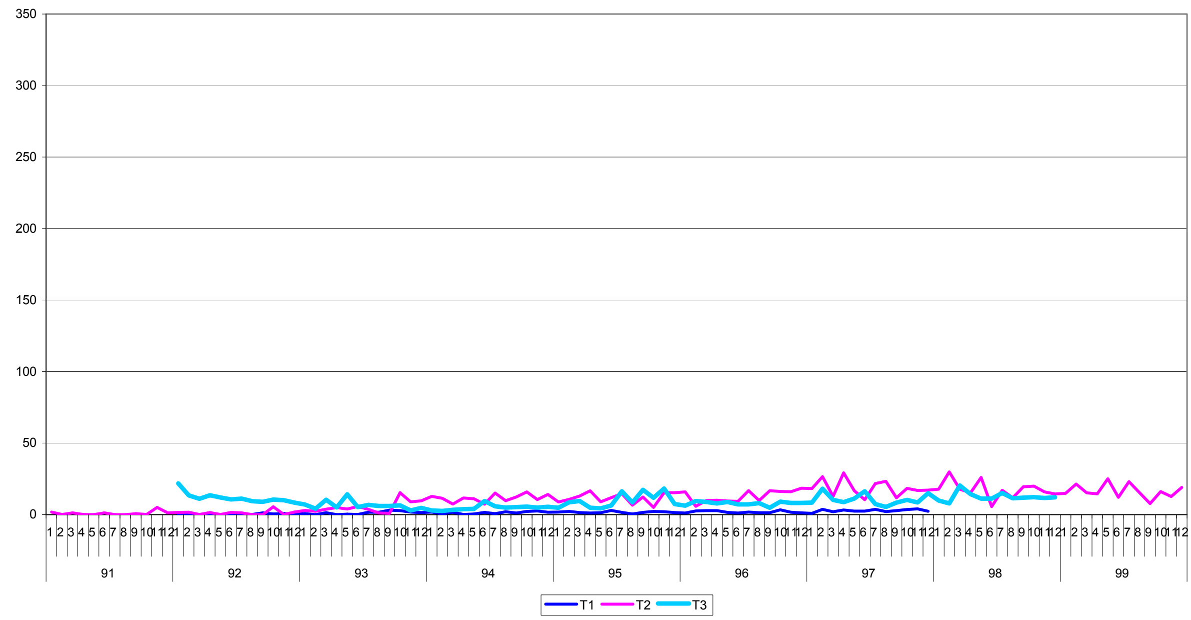


Figure 3. Total cargo handled by output category: Terminal 1

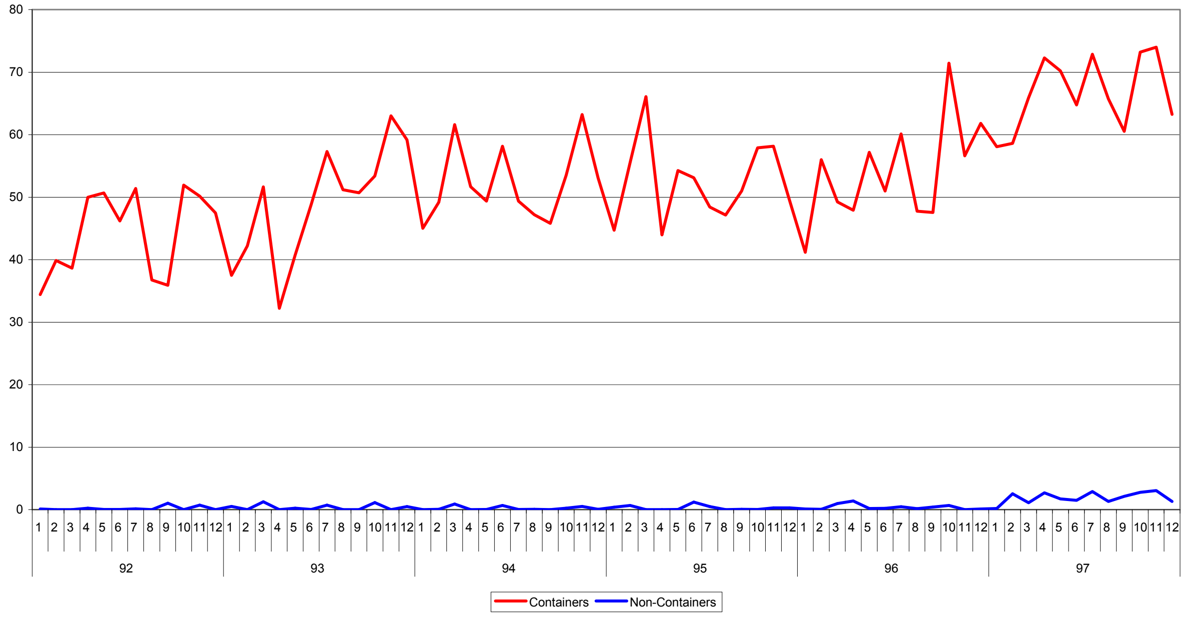


Figure 4. Total cargo handled by output category: Terminal 2

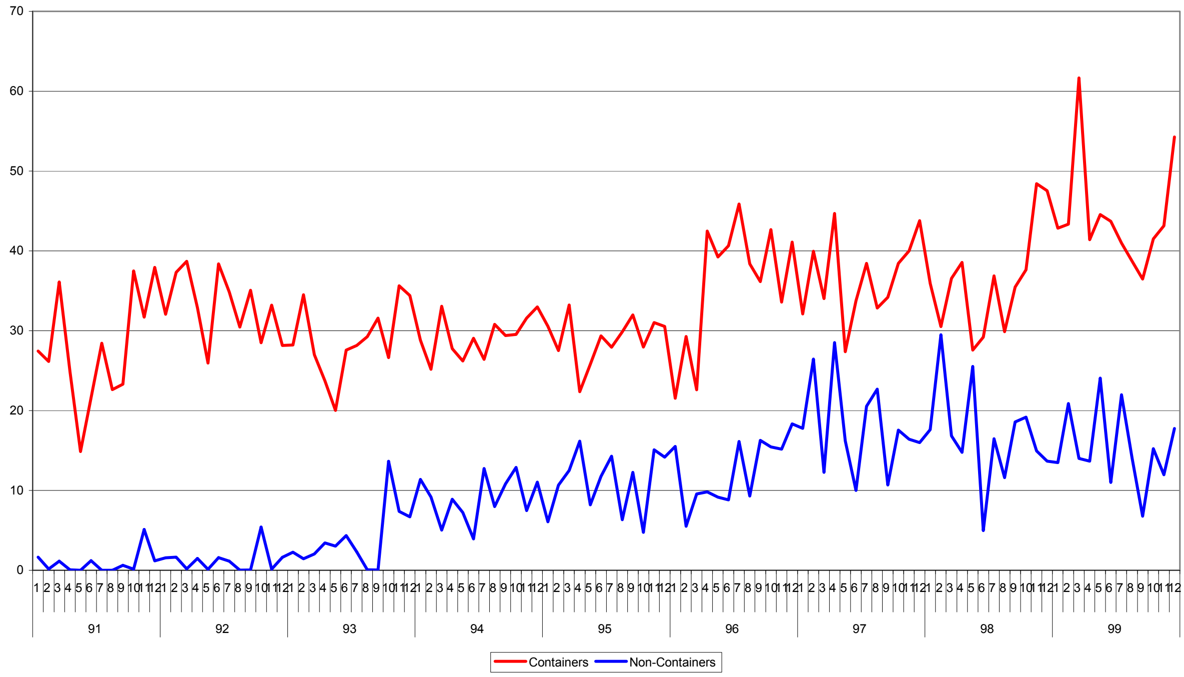
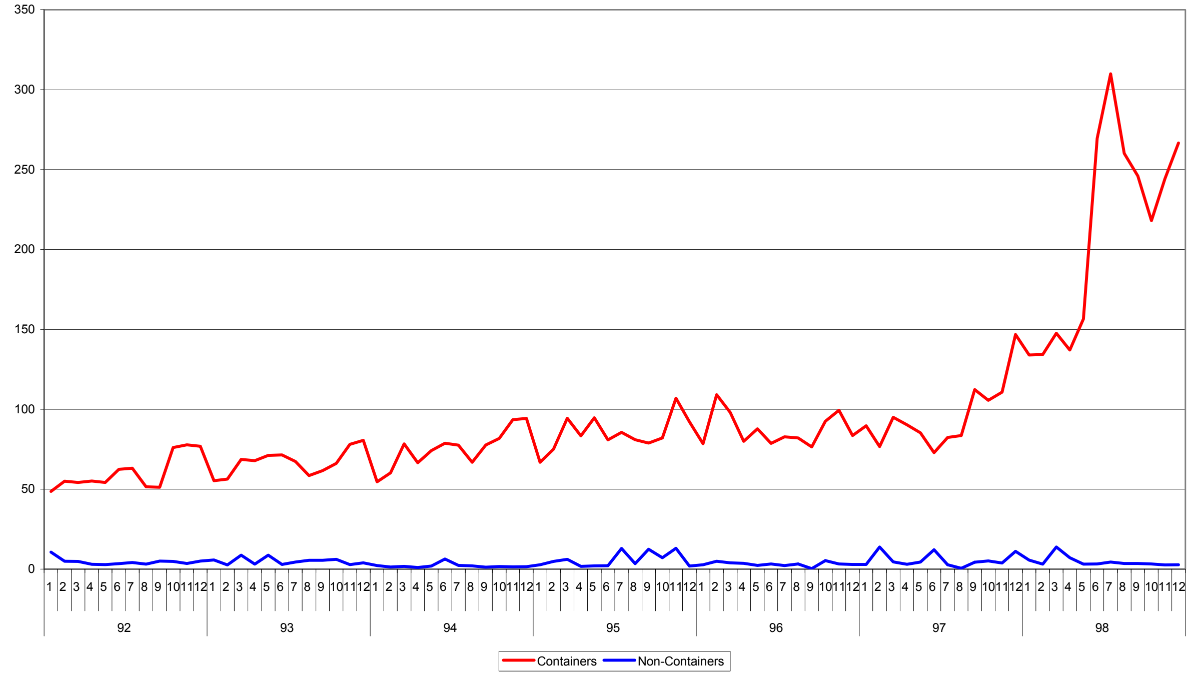


Figure 5. Total cargo handled by output category: Terminal 3



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