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Measuring Scale and Scope Economies with A Structural Model of Postal Delivery[1]

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1. Introduction

There is general recognition of the existence and importance of scale and scope economies in street delivery of postal items by both researchers and policy makers. The existence of such economies potentially affects issues such as the impact of competition on costs, the universal service obligation, and the vulnerability of posts to cherry-picking. If single firm production of delivery is cheaper than multi-firm production, then duplication of the postal network is wasteful. Examples of policy analyses that rely on economies in delivery are provided by Panzar (1991); Perkins (2001); Bernard et al (2002), Bradley, Colvin and Perkins (2002); Bradley, Colvin and Perkins (2004); d'Alcantara and Amerlynck (2005); and Crew and Kleindorfer ((2005).

Though there is evidence of economies in postal functions other than street delivery (see Bradley and Robinson (1988), Bradley and Colvin (1999), Cazals,

[1] The views expressed in this paper are those of the authors and do not necessarily reflect those of George Washington University, the United States Postal Service, or Howard University.

Duchemin et al (2001) and Gazzei, et al (2002)), the presence of economies in street delivery accords particularly well with intuition. A postal route is a classic network, embodying elements of network cost, such as travel to and from the route, as well as elements of cost that vary little with volume. Given that a carrier must approach (or 'access') an address to deliver a single item, the number of items that are delivered along with it, so long as such extremes as the upper weight limit on the carrier's satchel are not surpassed, will have no additional impact on cost. Intuition also tells us that putting two or more letters into the same box is unlikely to raise total delivery cost in a proportionate manner.

Despite general agreement on the phenomenon, there is relatively little quantitative estimation of economies in street delivery. Given the importance of delivery economies in various policy analyses, it is important to obtain reliable measures of their magnitude.

A second motivation for the current work is the evident need to determine the degree to which evolving street delivery operations may have influenced scale and scope economies. With technology changing rapidly in mail processing operations, including the 'inside work' of letter carriers, there could be ramifications for the street delivery function. In the United States, in particular, major changes have occurred in the recent past including advances in worksharing and mail processing automation. In addition, mail delivery has become increasingly motorized and there has been a rise in the relative share of parcel shaped products. These changes argue for an examination of economies in the new delivery environment.

In this paper, we investigate scale and scope economies in delivery while modeling the United States Postal Service's method for optimizing its delivery network. The Postal Service uses a two step process to structure its delivery network, and we specify a two equation recursive model to model this process. We estimate both equations using a recent delivery data set collected by the Postal Service. We then use the estimated equations to calculate measures of scale and scope economies in street time activities.

2. Previous Evidence on Economies in Street Delivery

Despite the importance this issue, there has been relatively little empirical evidence produced relative to economies in the street delivery function (often referred to as 'outside work'). Table 1 lists the research efforts on this topic, and indicates for each the methodology employed as well as the result, expressed in terms of an elasticity of cost with respect to output. Though the results are uniformly consonant with scale economies, i.e., exhibiting output elasticities significantly lower than one, they differ from each other in degree, due no doubt to differences in methodology chosen by the authors, as well as to differences in the underlying data.

Table 1

Estimates of Scale Economies

Authors	Data	Country	Model	Elasticity
Rogerson and Takis (1993)	PRC Data (R-1990-1)	U.S.	Summary of USPS methods	35%
Bradley and Colvin (1995)	Cross section of 15,550 routes	U.S.	Access equation (Poisson)	NA[2]
Cohen and Chu (1997)	PRC Data (R-1990-1)	U.S.	Disaggregation Impact	39%[3]

[2] Bradley and Colvin (1995) estimate product-specific scale returns, but not an overall elasticity.

[3] Cohen and Chu (1997) are primarily interested in cost subadditivity. However, relating their estimated reduction in cost to a putative halving of volume yields an output elasticity of 39%.

Cazals, et al (1997)	Cross section of 400 offices		Non-parametric	50%
Roy (1999)	Calibration data	France	Engineering model	82%
Cazals, et al (2001)	5-year panel of 8293 offices		Fixed effects, translog	60%
Cazals, et al (2004a)	Cross section of 4739 offices		Log-linear	23%
Cazals, et al (2004)	2-year panel of 509 offices	UK.	Random effects (log-linear).	42%

As discussed above, a fundamental intuition underlying the view that postal services are a natural monopoly concerns the nature of network access. Hence, to determine whether delivery costs are subadditive, Bradley and Colvin (1995) focused strictly on the 'access' portion of the street delivery function. They estimated a restricted access cost function that embodied a Poisson stop generating process first suggested by Jasinski and Steggles (1977). The authors noted the several interesting properties of this assumption on the distribution of mail across delivery points, and showed how the conditions for subadditivity of costs are met when the function is fit to US Postal Service data. Nevertheless, most other statistical work on scale and scope economies in the delivery function has utilized more flexible functional forms. Such work also attempts to measure scale and scope economies for the entire street delivery process.

Also interested in whether postal services are natural monopolies, Cohen and Chu (1997) estimated the total cost impact of splitting the U.S. Postal Service into two equally sized but separate organizations. They found the sum of the costs under the new arrangement to be greater than the costs of single firm delivery and attributed the cost difference to scale economies in street delivery.

Casals et al (1997) estimated a translog cost function, with environmental variables (density) included, from a cross section of 400 offices, finding costs to be subadditive. The authors suggest that that analysis suffers from an infirmity in translog approximation, one corrected by non-parametric methods. The application of such estimation methods yields an output elasticity in the range of 45 to 63 percent.

Similarly, Casals et al (2001) fit a translog model to a data set of La Poste offices over the 1994 thru 1998 period. They find an elasticity of 60 percent. Finally, Casals et al (2004b) worked with a two year panel of offices for the United Kingdom and found an output elasticity of 42 percent.

In sum, the empirical studies general have found output elasticities well less than 100 percent, implying substantial scale economies in delivery.

3. A Structural Model of Delivery.

In the United States, delivery areas are defined by Zip Codes. This is the level at which delivery is managed and at which resource allocations are made. This means that Zip Codes play the same role in an analysis of delivery costs that firms play in an industry cost study. They are the unit of economic decision making. We thus model the determination of delivery costs at the Zip Code level.

The Postal Service process of staffing delivery within a Zip Code is a two-step process. In the first step, the volumes to be delivered, the number of delivery points, and the geography of the delivery area are considered. In addition, the Postal Service is generally constrained to provide each carrier with a workday that is approximately eight hours, including both time in the office and time on the street. Small variations from the "eight hour day" are allowed in the planning process, but major ones are not. Note this does not constrain the amount of street time to be constant from route to route but the amount of total time, including street and office. Thus, a route with more office time responsibilities would, *ceteris paribus*, have less street time. Nevertheless, the "eight hour day" constraint is incorporated in the Postal Service optimization process.

The result of the first stage optimization is the optimal number of routes for serving the Zip Code. In the second stage, line of travel and the actual delivery points to be served by each route are determined. In this way, the scheduled time for each route is determined. Of course, from the perspective of the Zip Code (and total street time), the second step involves determining the average street time per route within the Zip Code. The second stage process is done taking the number of routes as constant and for each route determining the street time based upon the delivery volume, the delivery points to be served and geography.

We model the two-stage Postal Service street time determination process with a two equation recursive structural model. In the first step, the number of routes per Zip Code is determined and then, in the second step, the time per route within the Zip Code is determined. We thus specify the following model:

$$RTS_k = \beta_0 + \sum_{i=1}^{4} \beta_i X_{ik} + \sum_{j=1}^{4} \sum_{i=1}^{4} \beta_{ij} X_{ik} X_{jk} + \lambda_1 DP_k + \lambda_2 DP_k^2 + \lambda_3 \Theta_k + \lambda_4 \Theta_k^2 + \varepsilon_{rk}$$

$$ST_k = \gamma_0 + \sum_{i=1}^{4} \gamma_i X_{ik} + \sum_{j=1}^{4} \sum_{i=1}^{4} \gamma_{ij} X_{ik} X_{jk} + \delta_1 DP_k + \delta_2 DP_k^2 + \delta_3 \Theta_k + \delta_4 \Theta_k^2 + \delta_5 RTS_k + \delta_6 RTS_k^2 + \varepsilon_{dk}$$

In these equations, RTS stands for the number of routes in the Zip Code, X_i stands for one of the volumes to be delivered, DP stands for delivery points, and Θ stands for a geography variable. This model is structural in the sense that it provides the two behavioral equations that describe how street time is determined. To solve for the total amount of street time that would be caused by a given amount of volume, given the network (as defined by the delivery points and geography), one would have to solve the two equations for the reduce form. We do this later in the paper when we produce measures of scale and scope economies in delivery.

Note that we specify a quadratic functional form. We do this for three reasons. First, quadratic form is sufficiently flexible to allow for increasing, constant or decreasing returns to scale. Second, this functional form has been used successfully in the past to model street time. Third, unlike the translog, the quadratic is a flexible form that can accommodate zero volumes, an outcome which occurs regularly in our data set. Also note that volume can affect street time in two ways. First, volume will influence the number of routes. As volume increases or decreases, we would expect the number of routes to increase or decrease. Holding constant the average time per route, this would change total street time in the Zip Code. Second, change in volume could change the street time for each of the fixed number of routes in the Zip Code. By changing the average street time per route, volume could also affect the total street time in the Zip Code. Our model allows these effects to be interactive in the sense that an increase in the number of routes in a Zip Code could lead to a decrease in average time. This would occur if the elasticity of street time with respect to routes in the second equation is less than one hundred percent.

The last part of the specification is the definition of the volume vectors. The focus of our research in this paper is technological. We are testing for the existence of scale economies in the street time activity. Consequently we focus on constructing volume vectors that are consistent with that technological approach. We recognize that this formulation of volume vectors is not unique and different analyses may require different volume vectors. For example, an analysis focused on measuring product cost may require separate shape vectors because more specific or different unit costs would be required.

For this paper, we require the volume vectors to closely reflect the latest technologic and operational changes in delivery. In the United States, there have been two factors that have been the primary drivers of recent changes in the nature of delivery. Those two factors are worksharing and mail processing automation.

Worksharing allows a postal operator's customers to prepare the mail in a variety of ways that reduce the activities in which the postal operator must handle the mail. It also reduces the resources consumed by the postal operator in providing the service. Worksharing involves a variety of different actions, like presorting the mail to reduce the amount of mail processing required, or dropshipping the mail to reduce the transportation required.

For delivery, the relevant worksharing action is the preparation of mail that is "walk sequenced" by the mailer. This mail is arranged in delivery trays by the mailer in the order of the addresses to which the mail is delivered. Walk sequenced mail is also transported to the relevant delivery unit by the mailer. The result of these actions is that letter carriers can take this mail to his or her route with very little office time preparation. When the carrier can take the mail directly to the route, then it is not cased.

Advances in mail processing automation have also reduced the need to case mail by the carrier. Mail processing equipment can be used to arrange letter mail in “delivery point sequence.” For this mail, the Postal Service prepares trays of mail for the carrier with the included mail arranged in the order in which it will be delivered. Delivery point sequenced mail can thus be taken directly to the street without casing. Our first volume variable is thus “prepared mail.” This is the delivery point sequenced mail and that portion of walk sequenced mail that is not cased.

The result of these technological and operational changes is that the only mail that is cased is the non-machinable and residual letters, flats, the small amount of walk sequenced mail that must be cased and small parcels. (Small parcels are those that will fit into the carrier’s case and the customer’s mail receptacle.) Because of this, the Postal Service has, in recent years, adopted a single case approach in which all cased mail is cased together. That is, rather than sorting the letters and flats into separate cases, letter carriers now sort all cased mail for a given address into a single opening. When the casing is completed, the combined mail is pulled down together and taken to the street as a single bundle. Our second volume vector is the cased mail.

There is a final type of mail that the carrier delivers. We term this mail “customer contact mail,” and it consists of mail that cannot be simply left in the mail receptacle. This includes “large” parcels which require an attempt at direct delivery to the customers and “accountables” that necessarily require some form of customer contact. This mail makes up our third volume vector.

In addition to delivery, letter carriers in the United States collect a significant amount of mail from customers' receptacles. If a piece of mail has proper postage, a customer may leave the mail in the receptacle for the carrier to collect. Collection mail comprises our last volume vector.

4. The Data.

The data set consists of daily observations on the total street time and volumes delivered in a sample of Zip Codes. The observations were taking over a 2 week period (11 delivery days) in the spring of 2002. The Zip Codes were drawn in a stratified random sample. The regression data base consists of 145 Zip Codes. Sample statistics are provided below:

Table 2

Total Street Time (seconds)	325,336.5
Prepared Mail	27,361.4
Cased Mail	24,329.3
Collection Mail	4,969.5
Customer Contact Mail	217.2
Delivery Points	9,462.3
Routes	19.5

The final variable controls for the geographic density of the Zip Code. We use the number of delivery points per square mile of land in the Zip Code.

5. Empirical Results

We estimated the recursive structural model allowing for simultaneous correlation of the error terms. In addition, we calculated the heteroscedasticity corrected standard errors (HCSE). They are presented in the following tables along with the estimated coefficients.

The results for the routes equation conform to economic intuition and operational practice. Increases in volume delivered within a Zip Code lead to an increase in the number of routes required to provide the delivery service. To get a measure of the magnitude of the empirical results we calculate the effect on routes from adding 1,000 pieces per day (everyday) for each shape vector. For example, adding 1,000 pieces of cased mail on a sustained basis would require the addition of about 1/3 of a route (.29) whereas adding 1,000 pieces of customer contact mail per day would require and additional 2.87 routes.

Table 3

Dependent Variable: Number of Routes

Variable	Coefficient	HCSE
Intercept	-7.703E-01	3.528E-01
Prepared Mail	5.598E-05	2.405E-05
Prepared Mail^2	-9.884E-11	3.443E-10
Cased Mail	2.429E-04	1.954E-05
Cased Mail^2	-1.485E-09	2.091E-10
Collection Mail	8.892E-05	4.545E-05
Collection Mail^2	-5.496E-10	6.630E-10
Cust. Contact Mail	1.090E-03	2.120E-03
Cust. Contact Mail^2	-1.116E-05	2.320E-06
Prepared Mail*Cased Mail	6.610E-10	3.114E-10
Prepared Mail*Collection Mail	-7.752E-09	1.386E-09
Prepared Mail*Cust. Contact Mail	7.805E-08	5.373E-08
Cased Mail*Collection Mail	1.255E-08	1.326E-09
Cased Mail*Cust.Contact Mail	1.845E-07	6.468E-08
Collection Mail*Cust.Contact Mail	1.098E-09	1.181E-07
Delivery Points	1.340E-03	9.132E-05
Delivery Points2	-1.128E-08	3.129E-09
Density	5.820E-03	2.900E-03
Density^2	-1.216E-05	5.410E-06

# of Obs.	1,545	
R^2	0.885	

Table 4
Effects of Volume on Routes From Adding 1,000 Pieces Per Day to the Zip Code

Volume Vector	Increase in Routes	Elasticity of Routes
Prepared Mail	0.05	0.06
Cased Mail	0.29	0.35
Collection Mail	0.18	0.04
Cust. Contact Mail	2.87	0.03

Estimation of the delivery time equation produces the expected result that increases in the number of routes increase total time. We note that the increase in time is nonlinear, indicating that as routes are added the additional delivery time rises less than proportionately. In other words, the street time per route falls as more routes are added. In addition, we find that increases in the amount of cased mail in a Zip Code *reduce* the average street time per route. While this may seem counterintuitive, it is correct. As the amount of *cased* mail in a Zip Code increases, the amount of in-office time rises sharply and the average street time per route thus falls.

Table 5

Dependent Variable: Delivery Time

Variable	Coefficient	HCSE
Intercept	4.462E+03	3.360E+03
Prepared Mail	6.040E-01	2.303E-01
Prepared Mail^2	2.840E-06	3.280E-06
Cased Mail	-1.334E+00	2.269E-01
Cased Mail^2	3.400E-06	2.020E-06
Collection Mail	2.813E-01	4.421E-01
Collection Mail^2	8.390E-06	6.340E-06
Cust. Contact Mail	4.595E+01	2.053E+01
Cust. Contact Mail^2	5.200E-03	2.246E-02
Prepared Mail*Cased Mail	9.190E-06	3.070E-06
Prepared Mail*Collection Mail	-2.609E-05	1.330E-05
Prepared Mail*Cust. Contact Mail	-5.920E-04	5.185E-04
Cased Mail*Collection Mail	3.524E-05	1.359E-05
Cased Mail*Cust.Contact Mail	-5.474E-04	6.180E-04
Collection Mail*Cust.Contact Mail	-4.681E-04	1.120E-03
Delivery Points	3.046E+00	1.142E+00
Delivery Points2	1.051E-04	3.644E-05
Density	-1.692E+02	2.757E+01
Density^2	1.752E-01	5.150E-02
# of Routes	1.544E+04	6.579E+02
# of Routes^2	-2.714E+01	8.854E+00
# of Obs.	1,545	
R^2	0.963	

To get a measure of the size of the estimated coefficients, we calculated the effect of adding 1,000 pieces per day, for each volume vector on the average time per route. This shows, for example, that an increase of 1,000 pieces per day of prepared mail would lead to an additional 12 minutes of street time per route.

Table 6
Effects of Volume on Average Street Time Per Route

Volume Vector	**Change in Average Street Time Per Route (Minutes)**
Prepared Mail	12.1
Cased Mail	-14.3
Collection Mail	6.8
Cust. Contact Mail	272.8

6. Calculating Scale and Scope Economies in Delivery

Calculating scale economies[4] requires solving the structural model for the reduced form and then calculating the overall effect of a change in volume on street time. Both the effect of a volume change on routes and the effect of a volume change on average time per route must be accounted for in the calculation. Solving the model for the measure of overall scale economy yields:

[4] Some authors distinguish between network economies in delivery and economies of scale (see Casals et al 2004b). In this paper, we use the term 'economies of scale' to refer to a less than proportionate increase in delivery costs that occurs in response to a sustained increase in volume (or traffic), when other influences on cost (such as the size of the network) are held constant.

$$\lambda_N = \left[\frac{\begin{array}{l} \gamma_0 + \sum_{i=1}^{4} \gamma_i X_{ik} + \sum_{j=1}^{4} \sum_{i=1}^{4} \gamma_{ij} X_{ik} X_{jk} + \delta_1 DP_k + \delta_2 DP_k^2 + \delta_3 \Theta_k + \delta_4 \Theta_k^2 \\ + \delta_5 \left[\begin{array}{l} \beta_0 + \sum_{i=1}^{4} \beta_i X_{ik} + \sum_{j=1}^{4} \sum_{i=1}^{4} \beta_{ij} X_{ik} X_{jk} + \lambda_1 DP_k + \lambda_2 DP_k^2 \\ + \lambda_3 \Theta_k + \lambda_4 \Theta_k^2 \end{array} \right] \\ + \delta_6 \left[\begin{array}{l} \beta_0 + \sum_{i=1}^{4} \beta_i X_{ik} + \sum_{j=1}^{4} \sum_{i=1}^{4} \beta_{ij} X_{ik} X_{jk} + \lambda_1 DP_k + \lambda_2 DP_k^2 \\ + \lambda_3 \Theta_k + \lambda_4 \Theta_k^2 \end{array} \right]^2 \end{array}}{\sum_{i=1}^{4} \left[\left(\gamma_i + 2\gamma_{ii} X_i + \sum_{j \neq i} \gamma_{ij} X_j \right) + \left(\delta_5 + 2\delta_6 \, RTS \right) \left(\beta_i + 2\beta_{ii} + \sum_{j \neq i} \beta_{ij} X_j \right) \right] X_i} \right]$$

Using the estimated regression parameters and the mean values for the variables to calculate the estimated value for scale economies yields an overall measure of scale economy equal to 2.327. A value this large implies substantial economies of scale in street time (the corresponding output elasticity is 42.9 percent).

The other aspect of economies in street time is scope. The visual image of multiple carriers, each delivering a single product epitomizes the inefficiencies associated with the failure to capture economies of scope. However, the amount of savings from joint production depends upon how much of the carriers' time would actually be replicated by a system of repeated accesses. This is exactly what the product specific and overall economies of scope measure provides. The product specific economies of scope measure indicates how much additional time the Postal Service would incur if it were to deliver the product in question separately from all other products. Given our structural model, economies of scope arise both in the efficient configuration of routes and from an efficiencies that occur with in the routes. Both must be accounted for in the scope economies measure. The mathematical formula for calculating product-specific scope economies is given by:

$$\sigma_i = \frac{\begin{aligned}&\gamma_0 - \sum_{j \neq i} \gamma_{ij}\, X_{ik} X_{jk} + \delta_1\, DP_k + \delta_2\, DP_k^2 + \delta_3\, \Theta_k + \delta_4\, \Theta_k^2 \\ &+ \delta_5 \left[\begin{aligned}&\beta_0 - \sum_{i \neq j} \beta_{ij}\, X_{ik} X_{jk} + \lambda_1\, DP_k + \lambda_2\, DP_k^2 \\ &+ \lambda_3\, \Theta_k + \lambda_4\, \Theta_k^2\end{aligned} \right] \\ &+ \delta_6 \left[\begin{aligned}&\beta_0 - \sum_{i \neq j} \beta_{ij}\, X_{ik} X_{jk} + \lambda_1\, DP_k + \lambda_2\, DP_k^2 \\ &+ \lambda_3\, \Theta_k + \lambda_4\, \Theta_k^2\end{aligned} \right]^2\end{aligned}}{ST(\overline{X}, \overline{DP}, \overline{\Theta})}$$

The empirical measures of scope economies are derived by numerically computing the values for each product using the estimated parameters from the structural equations. The resulting values indicate the percentage increase in street time that the Postal Service would incur from delivering the specific product by itself. For example, the Postal Service would incur 61.6 percent more time from delivering sequenced mail by itself and handling the other products (cased mail, collection mail, and customer contact mail) as a group. Similarly collecting mail separately from delivery would lead to a 58.5 percent increase in street time. A review of the individual structural equations suggests that most of the scope economies result from the impact of volume on the number of routes, as opposed to the impact on average time per route. The ability of the Postal Service to optimally determine its route structure for the joint delivery of mail leads to substantial cost savings.

Table 7
Product Specific Economies of Scope Measures for
Street Time

Volume Vector	**Scope Economies Measure**
Prepared Mail	61.6
Cased Mail	45.3
Collection Mail	58.5
Cust. Contact Mail	56.3

Finally, we can calculate an overall measure of scope economies. This value measures how much more street time the Postal Service would need to delivery each of the four volume vectors by itself. The formula for the overall scope economies measure in our structural model is given by:

$$\sigma_N = \frac{\begin{array}{l} \sum_{i=1}^{4}\left(\gamma_0 + \gamma_i \; X_i + \gamma_{ii} \; X_i^2 + \delta_1 \, DP + \delta_2 \, DP^2 + \delta_3 \, \Theta \; + \delta_4 \, \Theta^2\right) \\ + \quad \sum_{i=1}^{4} \delta_5 \begin{bmatrix} \beta_0 + \beta_i \; X_i + \beta_{ii} \; X_i^2 + \lambda_1 \, DP \; + \lambda_2 \, DP^2 \\ + \lambda_3 \, \Theta \; + \lambda_4 \, \Theta^2 \end{bmatrix} \\ + \quad \sum_{i=1}^{4} \delta_6 \begin{bmatrix} \beta_0 + \beta_i \; X_i + \beta_{ii} \; X_i^2 + \lambda_1 \, DP \; + \lambda_2 \, DP^2 \\ + \lambda_3 \, \Theta \; + \lambda_4 \, \Theta^2 \end{bmatrix}^2 \quad - \quad ST(\overline{X}, \overline{DP}, \overline{\Theta}) \end{array}}{ST(\overline{X}, \overline{DP}, \overline{\Theta})}$$

Computation of the overall scope economies measure yields a value of 1.662. This means that street time would rise by over 166 percent if the Postal Service were to deliver the individual products by themselves and collect the mail separately.

7. Conclusion

We have built a structural model of delivery "street" time that embodies the key aspects of the actual optimization process the Postal Service follows in constructing its carrier delivery network. We model the two-step Postal Service process in which the number of routes in a delivery area is specified first, followed by a specification of the street time to be taken on each route.

We estimate an econometric version of the model using recent Postal Service data and an updated set of volume vectors that reflects recent technological and operational changes in delivery. We then use the econometric version of the model to calculate formal measures of scale economies and scope economies in street time activities. We find evidence for both large scale economies and large scope economies. This means Postal Services large and relatively fixed delivery network provides substantial benefits to the U.S. economy in the form of material reductions in delivery cost.

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