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The Price-Size Curve and Planting Density Decisions[1]

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ABSTRACT. The planting density decision is influenced by the price-size relationship existing between the tree crop grown and the products sold. Several price-size curves are presented, and their impact on the optimal economic planting density is evaluated. Results indicate that when the price-size curve is upward sloping, fairly low planting densities may be appropriate. Higher densities apply when the price-size curve is flat. Sensitivity analysis is carried out to evaluate the impact of changing site index and discount rate on the density decision.

South. J. Appl. For. 16(1):24–29.

Financial returns from plantation investments are influenced by a multitude of factors. These include planting density, rotation age, site index, planting and management costs, product price, and thinning regimes. The optimal planting density, in turn, is influenced by the relationship existing between the size of the trees being grown and the value of the products that can be sold. This "price-size" relationship has important implications for management decisions.

Several researchers have examined the question of optimal economic planting density. The work of Bowling (1986) and Conrad et al. (1990) employs case studies based on results from experimental plot data. Other studies, notably those of Borders et al. (1991), Bailey (1986), Pienaar (1977), Hotvedt and Straka (1987), and Broderick et al. (1982) are based on the results of computerized growth and yield models. A variety of economic and biological assumptions is built into all of these studies. Not surprisingly, no universal agreement exists regarding what constitutes an optimal planting density.

Bowling (1986), using a replicated slash pine (*Pinus elliottii* Engelm.) spacing study in Georgia, suggested that densities as low as 400 trees/ac may be appropriate when products such as chip-n-saw and sawtimber can be merchandised. Similar conclusions were reached by Conrad et al. (1990) for a nonthinned loblolly pine (*Pinus taeda* L.) plantation. Their analysis of a spacing study in Mississippi showed that the lowest density examined, 484 trees/ac (tpa), resulted in the greatest economic returns when multiple products were considered.

Other research indicates that the economically optimal planting density varies within wide limits. Borders et al. (1991), for example, showed that on SI 60 (base 25) land, the appropriate planting density for nonthinned loblolly pine can range from 590 to 1300 tpa, when factors such as variable site preparation, planting, and transportation costs are considered. Bailey (1986) came to similar conclusions for both slash and loblolly pine.

Hotvedt and Straka (1987) reported that planting densities from 750 to 950 tpa combined with thinning led to the highest economic returns. Broderick et al. (1982) also recommended thinning to maximize investment returns. However, they also recommended planting at much lower densities (436 tpa).

Operationally, a wide range of densities is employed for tree planting in the South, reflecting the diversity of products grown by different owners. Several forest products firms contacted by the authors reported densities ranging from 450 tpa for trees intended as sawtimber to 1100 tpa for pulp stands. At least one large consulting firm (Vardaman 1989) recommends that nonindustrial owners wishing to grow multiple products plant at densities as low as 300 tpa. A regionwide average planting density reported by Straka et al. (1989) is 700 tpa.

Some workers (Borders et al 1991, Conrad et al. 1990, Broderick et al. 1982) view price-size relationships as "lumpy," in the sense that discrete per-unit prices apply to trees grown for products such as pulp, chip-n-saw, and sawtimber, regardless of tree diameter. Tree value is viewed as constant from the time a stem attains the minimum usable dimension for a specific product until the time it can be used for the next higher valued product (Marshall 1990).

The work of Hotvedt and Straka (1987) differs from other work because their analysis employs a residual value approach to timber valuation. They obtain stumpage values by subtracting manufacturing, transportation, and harvesting costs from end-product prices, to derive "returns-to-tree" curves for trees of differing dbh.

This paper discusses first, several types of price-size relation-

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[1] Alabama Agricultural Experiment Station Series No. 9-912833P.

ships which can exist, and the kinds of situations to which they may apply. The influence of these different price-size curves on planting density decisions for nonthinned loblolly pine plantations is examined. Thinning is not considered here because the practice does not seem to be widely applied. A 1986 Auburn University telephone suvey of 35 timberland-owning forest products firms in the South indicated that commercial thinning was employed regularly as a management practice by a small minority of firms.

METHODS

Price-Size Relationships

The shape of a price-size curve depends on the value of the intended end-product of the harvested trees. The simplest case is a horizontal line of price per unit volume over dbh. This implies that tree size does not influence the stumpage price paid per unit volume. A horizontal price-size curve may be appropriate when trees are grown exclusively for pulpwood. In this study, two different horizontal price-size curves were examined for pulpwood (Figure 1). These assume pulpwood is valued at $25/cunit and $50/cunit, respectively. The lower price reflects 1990 average prices in southern Alabama as reported in Timber Mart South (1990).

A positively sloped price-size curve implies that trees are used for increasingly higher value products and/or that harvesting and transportation costs decrease per unit volume of product as dbh increases. Several multiple-product curves are considered in this study (Figure 2).

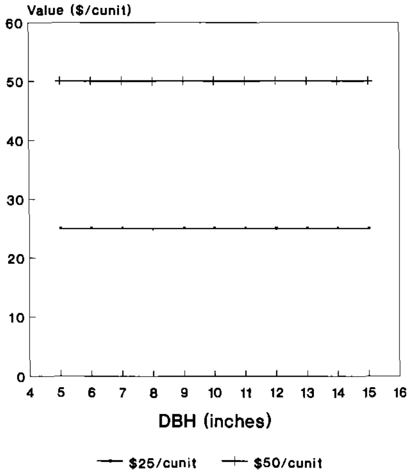

Figure 1. Pulpwood price-size curves.

Marshall (1990) derived price-size relationships using the residual value method and a hypothetical sawmill study. He determined stumpage value by beginning with sawn timber values and subtracting milling costs, losses from sawing, transportation and harvesting costs. Marshall developed the curves on a per-tree basis, which we converted to a per-cunit basis for this study. Unlike the return-to-tree curves derived by Hotvedt and Straka (1987), which did not value trees smaller than 9 in. in dbh, Marshall included pulpwood stems as small as 5 in. dbh. In his analysis it was assumed that the minimum inside-bark small end diameters were 3 and 6 in. for pulp and sawtimber, respectively.

A second price-size curve was provided by a forest products firm operating in Alabama. The firm is primarily a paper producer, but trees larger than 12 in. dbh are merchandised as chip-n-saw material to a 6 in. top, inside bark. The firm values material from trees 5 to 12 in. dbh at a constant stumpage price of $32.50 per cunit, with a minimum top diameter of 3 in. Trees larger than 12 in. are valued at a constantly increasing rate per cunit of $2.50 per in. of added dbh. The curves provided by Marshall and the forest products firm (the Marshall and Company curves) are appropriate for use by integrated forest products firms that purchase wood from their own woodlands or from private landowners. But the majority of timberlands in the South are owned by nonindustrial owners. Most of these landowners do not have access to the type of mill study required to derive the Marshall and Company price-size curves. For these individuals, price-size relationships require a different approach.

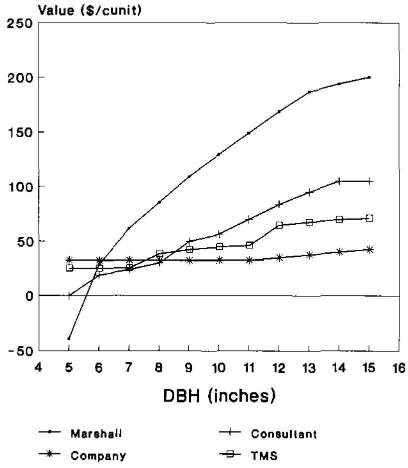

Figure 2. Multiple-product price-size curves (TMS = Timber Mart South).

An example of a price-size curve employed by a consulting forester (the Consultant curve) was derived by surveying and observing the amount that local wood buyers are willing to pay for timber of a given size (Vardaman 1989).

Finally, a price-size curve derived from Timber Mart South (the TMS curve) was derived using 1990 stumpage prices for pulp, chip-n-saw, and sawtimber in southern Alabama. It assumes that trees 5 in. in dbh and larger can be utilized as pulp to a 4 in. top, inside bark. Chip-n-saw can be cut from trees 8 in. dbh and up to a 6 in. top, and sawtimber can be cut from trees 12 in. dbh and up to an 8 in. top.

The TMS curve is flat for trees 5 to 8 in. dbh because only pulpwood can be cut from such trees. For trees 8 in. and larger, however, the curve steps up, then has a positive slope up to 12 in. As trees become merchantable as sawtimber, the curve again steps up and has a positive slope. The positive slopes following the upward steps occur because as trees enter successively higher value categories, part of the tree can be sold as pulpwood and part as sawtimber. For example, an 8 in. tree can be sold partly as small sawtimber and partly as pulpwood. A 10 in. tree, however, has a greater proportion of higher value chip-n-saw relative to pulpwood. Its value, calculated as a weighted average of the pulpwood and chip-n-saw material, is higher than that of an 8 in. tree.

As seen in Figure 2, there is considerable diversity between the per cunit values for different size trees. The Marshall curve, for example, with values of up to $200/cunit probably provides an extremely optimistic upper bound on timber values. More important, the curves are not directly comparable because different assumptions regarding merchantability limits, stumpage price regions, and the type of timber seller apply to each one. The intent here is not to compare the curves to one another. Rather, they are used to show first, how price-size relationships can vary depending on the timber seller or buyer. Second, as shall be seen, the type of curve employed influences planting density decisions.

Generation of Stand Values

For each price-size curve the optimum rotation age was calculated using the Land Expectation Value (LEV) criterion for each of a set of different initial planting densities. The N.C. State Growth and Yield Simulator (Hafley and Smith 1989) was used to generate stand tables for each possible rotation age, at each density, for a given site index. The data in that model include spacing studies with densities as low as 300 tpa. This was used to define the minimum density examined here to avoid extrapolating beyond the model data set.

Planting densities of 300, 350, 400, 450, 500, 600, 700, and 900 trees/ac were examined. The optimum rotation for a given density is the age at which LEV is at a maximum. LEV is the discounted value of the net returns from an infinite series of identical rotations (Clutter et al. 1983).

By selecting the maximum LEV-age combination for each density, a potential problem is avoided. Sometimes researchers evaluate management alternatives at specific rotation ages, e.g., age 25, which can introduce a bias into the results. This occurs because the maximum LEV achieved using one management regime may differ substantially from that of another regime. In this analysis, the maximum LEV for one density may occur at age 30,versus age 25 for another density. If age 25 were used to compare two different densities, the results would be biased in favor of the regime which maximizes LEV at the younger age.

A 6% real discount rate was employed in the base-case, and LEVs are calculated on a before-tax basis. The analysis assumes that there is no increase in the real price of any product.

A site index of 60 at age 25 is assumed for the base-case. Stand values at each age were determined by summing the product of the cunit volume for the trees in each 1 in. diameter class by appropriate per-cunit prices. It was assumed that first-year survival of planted trees was 85%, and that survival percentage did not vary with planting density.

In calculating the LEVs, it was recognized that planting costs vary with different planting densities. Seedlings were valued at $0.028 each, and planting cost $0.058 per seedling. Site preparation was assumed to be constant for each planting density and consisted of chemical site prep plus burning at $91.34/ac (Straka et al. 1989). The analysis also assumes that the price-size curve does not change with stand density or rotation age. This last aspect will be discussed in greater detail later.

Sensitivity Tests

As indicated previously, the planting density decision is influenced by a number of interrelated factors. To examine these, site index and the discount rate were varied. In addition to the base-case SI of 60, site indexes of 50 and 70 were evaluated. A 4% discount rate was examined in addition to the base-case rate of 6%.

RESULTS AND DISCUSSION

Base-Case

Figure 3 shows the relationship between LEV and planting density for the base-case, multiple product price-size curves. For the Marshall, Consultant, and TMS price-size curves, LEV is at a maximum at 300 stems/ac and decreases with increasing density. For the Company price-size curve, LEV is at a maximum at a density of 500 tpa.

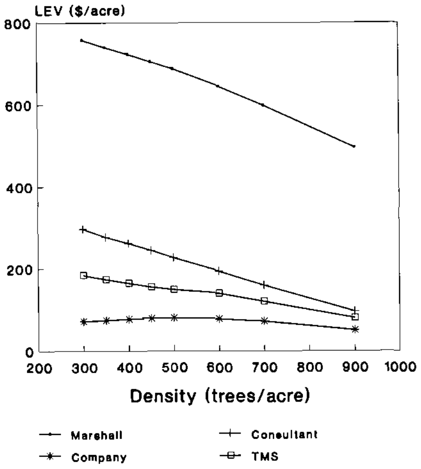

Figure 3. Land expectation value (LEV) over density, multiple product price-size curves, SI 60, 6% Discount Rate.

Table 1 shows these relationships more distinctly, and includes the rotation age at each density level for which LEV is at a maximum. Although a density of 300 tpa was optimal for all the multiple product curves except for the Company curve, the decrease in LEV going from 300 tpa to about 400 tpa is not large. For the Marshall, Consultant, and TMS curves the decrease is 5%, 12%, and 10%, respectively. At densities greater than 400 tpa, the percentage decrease in LEV gets larger. For a density of 900 tpa, the decreases are 36%, 90%, and 43%, compared to the lowest density.

Several implications can be drawn from Table 1. First, an upward sloping price-size curve suggests that lower planting densities may be preferable to higher planting densities. In 3 of the four cases, the lowest density examined had the highest LEV. But for a fairly wide range of densities, the reduction in LEV is minor. Therefore, if survival rates are typically lower than 85%, planting at higher densities may be justified.

The Company curve (Table 1)

Table 1. Land expectation values and optimal rotation ages for multiple-product price-size curve, base-case.[1]

Density/ age	Marshall	Consultant	Company	Timber Mart South
	LEV in $/ac, age in yr			
300	758.31*	296.65*	72.33	184.30*
Age	30	31	28	31
350	739.93	276.62	74.25	174.01
Age	29	31	27	30
400	723.38	261.36	76.95	164.94
Age	29	31	25	29
450	705.03	244.66	79.05	156.38
Age	28	30	25	28
500	687.36	226.70	80.17*	149.37
Age	28	29	24	27
600	645.45	194.32	78.47	140.70
Age	27	29	24	26
700	599.15	160.11	72.12	120.65
Age	27	29	24	26
900	496.97	96.31	50.52	79.96
Age	27	29	23	26

[1] Site Index 60 (base 25), 6% real discount rate, 85% first-year survival, before-tax analysis. Optimal density denoted by an asterisk.

shows an optimal density of 500 tpa. This results from a price-size curve that is flat until trees reach a threshold DBH of 12 inches, at which time they become usable as chip-n-saw material.

Figure 4 shows LEV over density for the pulpwood only price-size curves, using the base-level assumptions. With pulpwood at $25/cunit, LEV is maximized at 450 stems/ac. At $50/cunit, LEV is maximized at 600 tpa. For flat (or, in the case of the Company curve, almost flat) price-size curves, optimal planting densities tend to be higher than when curves slope upward. For the flat pulpwood price-size curves, the optimal planting densities in each case (450 and 600, respectively) are higher than for the Marshall, Consultant, and TMS curves.

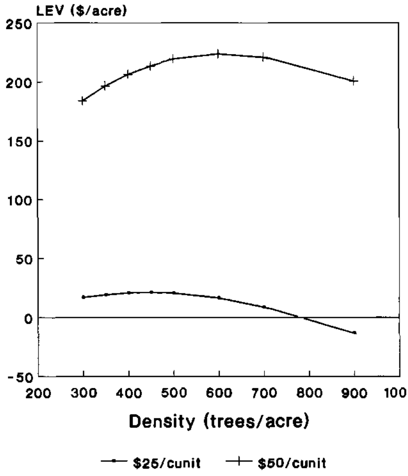

Figure 4. LEV over density, pulpwood price-size curves, SI 60, 6% discount rate.

Table 2 shows an interesting result. The optimal density (450 tpa) for $25/cunit pulpwood is considerably lower than for $50/cunit pulpwood or for the Company price-size curve. This implies that planting density is influenced not only by the slope of the curve, but also by the absolute magnitude of stumpage prices. The $25/cunit price-size curve is lower than either the Company curve or the $50/cunit curve.

In this case the planting density decision is driven more by cost and the discounting period than by timber value. The lower cost of planting fewer trees impacts the density decision more at lower stumpage prices. A lower stumpage price for a specific product increases the optimal rotation age (Chang 1984), so establishment costs are compounded over a longer period. In sum, the combined effect of a lower stumpage price, lower cost, and the resulting longer rotation implies a lower planting density.

Sensitivity Tests

Decreasing site index to 50 ft decreased volume at each age and density, and increasing SI to 70 increased volume. LEV therefore decreased and increased, respectively. For the Marshall, Consultant, and TMS curves, the planting density decision was unaffected, and the optimal density remained at 300 tpa for all site index levels. This was also true when the discount rate was varied to 4%, versus 6% for the base-case (Table 3). When the price-size curves had a fairly steep positive slope (Marshall, Consultant, and TMS curves), the density decision was not sensitive to either site index or discount rate for the range of densities examined.

The flatter price-size curves were more sensitive to changes in site index. For the Company curve the optimal planting density increased with site index, going from 450 tpa for SI 50 to 500 for SI 60 and 70, using a 6% discount rate. When the discount rate was decreased to 4%, the optimal density went as high as 600 tpa (Table 3).

A similar relationship was observed with the two pulpwood price-size curves. Optimal density went from 300 tpa for the $25/cunit curve at SI 50 to 500 tpa at SI 70 for the 6% discount rate (Table 3). Note, however, that at SI 50 all LEVs were negative at a 6% rate, meaning that a density of 300 tpa simply resulted in the smallest monetary loss. This indicates that at low prices and low site index levels the density decision is cost driven.

For the $50/cunit curve, the optimal density was as high as 600 tpa for SI 60 and 70 for both the 6% and 4% discount rates (Table 3). This suggests that the planting density decision is more sensitive when the price-size curve is flat, versus the situation when the curve has a steep upward slope. Although the densities differ, the general results here are consistent with the work of Borders et al. (1991). In their paper, increasing SI also resulted in an increase in optimal planting density.

Table 2. Land expectation values and optimal rotation ages for pulpwood price-size curves, base-case.[1]

	LEV in $/ac, age in yr	
Density/age	$25/cunit	$50/cunit
300	16.83	183.80
Age	26	26
350	19.17	196.43
Age	26	25
400	20.88	206.45
Age	25	24
450	21.52*	213.76
Age	25	24
500	20.51	219.41
Age	25	24
600	16.56	223.79*
Age	24	23
700	9.04	221.15
Age	24	23
900	−13.04	200.81
Age	24	23

[1] Site Index 60 (base 25), 6% real discount rate, 85% first-year survival, before-tax analysis. Optimal density denoted by an asterisk.

As in the base-case, the difference between LEV for the optimal density and a wide range of densities was small. For example, at SI 50 (6% discount rate) for the Marshall curve, there is only a 10% decrease in LEV as density goes from 300 tpa to 500 tpa. For SI 70 the decrease is 9%. This suggests that considerable leeway exists in density decisions when the assumptions regarding survival rates differ from those here.

The analysis assumes that the price-size curve is unaffected by stand density or by differences in rotation age of up to 5 years. Since both density and rotation length do influence the production of mature wood, they can influence the value of wood sold for pulp and solid wood products. However, for unthinned stands in the coastal plain, planting density does not affect the age of onset of mature wood formation (Clark and Saucier 1989, Gibson and Clason 1991). Therefore, the relative amount of juvenile wood produced by a given age can be approximated using a growth and yield model. Assuming that juvenile wood formation is completed by age 14 (Szymanski and Tauer 1991), the proportion of basal area in juvenile wood is calculated by dividing the basal area of the average tree in a stand at that age by the basal area of the average tree at harvest age. Table 4 shows that, although the size of the juvenile core is larger for loblolly pine grown at 300 tpa, the proportion of basal area in juvenile wood is slightly reduced for any economically optimal harvest age (22 to 31 years).

Table 3. Sensitivity analysis results from changing site index and discount rate assumptions from base-case.[1]

		6% discount rate, highest LEVs, optimal densities and rotations					
Site index		Marshall	Consultant	Company	TMS	Pulp at: $25/cnt	$50/cnt
50	Density	300	300	450	300	300	500
	LEV	324.95	80.29	−11.24	30.69	−43.84	72.42
	Age	32	35	29	34	30	26
60	Density	300	300	500	300	450	600
	LEV	758.31	296.65	80.17	184.30	21.52	223.79
	Age	30	31	24	31	25	23
70	Density	300	300	500	300	500	600
	LEV	1318.22	584.04	190.06	384.36	102.55	369.67
	Age	28	29	23	28	23	22

		4% discount rate, highest LEVs, optimal densities and rotations					
Site index		Marshall	Consultant	Company	TMS	Pulp at: $25/cnt	$50/cnt
50	Density	300	300	500	300	450	600
	LEV	878.46	338.56	118.50	219.70	46.33	294.26
	Age	36	37	30	37	29	28
60	Density	300	300	600	300	500	600
	LEV	1766.28	790.83	292.27	536.82	175.20	572.81
	Age	33	34	25	33	27	25
70	Density	300	300	600	300	500	600
	LEV	2852.27	1361.88	499.69	926.09	324.17	885.50
	Age	31	31	24	30	25	23

[1] Base-case assumes site index 60, 6% real discount rate, 85% first-year survival, before-tax analysis.

However, a lower rotation age increases the proportion of basal area in juvenile wood and can reduce pulp yield/cunit. In the base-case (Table 1), the rotation which maximizes LEV for trees planted at 900 tpa occurs 2 to 5 years earlier than for a density of 300 tpa. For the Timber Mart South price-size curve, harvesting a 300 tpa stand at age 31 rather than 26 years (at 600 to 900 tpa) lowers the percentage of basal area in juvenile wood by about 10% (Table 4). However, as long as pulpwood is purchased at the mill on a green weight basis, this advantage is not likely to be reflected in the stumpage price.

Commercial acceptance and suitability of wood as dimension lumber is largely influenced by knots (Koch 1972, Brazier 1977). Without pruning, wide spacings can result in larger knots, possibly decreasing the production of better lumber grades (Bennett 1969). However, for densities ranging from 300 to 1000 tpa, the effect of density on knot size is relatively small compared to the densities in the 100 to 300 tpa range (Clason

Table 4. The influence of spacing on dbh at age 14 and the approximate percentage of basal area (BA) in juvenile wood at various harvest ages (site index 60, Upper Coastal Plain model—NCSU Plantation Management Simulator).

Planting density/ac	dbh at age 14 (in.)	Harvest age (yr)					
		22	24	26	28	30	31
		Proportion of BA in juvenile wood (%)[1]					
300	6.4	51	45	42	39	36	35
600	5.7	53	49	45	42	39	38
900	5.2	54	49	46	41	39	37

[1] Proportion of BA in juvenile wood = BA of average tree at age 14/BA of average tree at harvest.

1991, pers. comm., Bennett 1969, Oberg 1989). If the production of high grade lumber is a management objective of the landowner, then greater production of clear wood can be achieved with wide spacing and pruning instead of relying on close spacing and natural pruning (Clason 1991, pers. comm., Bennett 1969, Bredenkamp et al. 1983, Fremlin 1981, Wessels 1987). Although the effects of density and pruning on the price-size curve are important issues, these topics are beyond the scope of this paper.

SUMMARY AND CONCLUSIONS

The price-size relationship which prevails for a specific ownership situation has a decided influence on the planting density decision. The analysis indicates that for nonthinned loblolly pine plantations, fairly low planting densities may be appropriate when multiple-product, positively sloped price size curves apply. Lower densities may also be warranted when the price-size curve is flat and stumpage prices are low. It is important to recognize that the results hinge on the assumption that low densities do not negatively impact wood value.

The results suggest lower densities for nonthinned stands than those recommended by some researchers (Borders et al. 1991, Bailey 1986) but are consistent with the findings of others (Conrad et al. 1990, Bowling 1986). Obviously the growth and yield model employed, along with the biological and economic assumptions built into any analysis, will influence the results. This study employed a different growth and yield model than any of the work cited which relied on computerized projection models. It is therefore interesting to note that the results here agree fairly closely with research which relies on experimental plot data.

Few industrial timber growers currently plant trees at stockings as low as 300 tpa, even where low prices prevail. There are several reasons for this. First, foresters frequently argue that more stems are needed in case survival is low. Also, planting at low densities may lead to increased weed competition and therefore reduced growth of the tree crop. Both are reasonable arguments, but Bredenkamp et al. (1983) have suggested that with respect to loblolly and slash pine, trying to control weeds with stand stocking is poor silviculture. Future research will more completely answer these questions. ☐

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