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SECOND-ORDER SCHEDULES OF TOKEN REINFORCEMENT WITH PIGEONS: IMPLICATIONS FOR UNIT PRICE

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Four pigeons were exposed to second-order schedules of token reinforcement, with stimulus lights serving as token reinforcers. Tokens were earned according to a fixed-ratio (token-production) schedule, with the opportunity to exchange tokens for food (exchange period) occurring after a fixed number had been produced (exchange-production ratio). The token-production and exchange-production ratios were manipulated systematically across conditions. Response rates varied inversely with the token-production ratio at each exchange-production ratio. Response rates also varied inversely with the exchange-production ratio at each token-production ratio, particularly at the higher token-production ratios. At higher token-production and exchange-production ratios, response rates increased in token-production segments closer to exchange periods and food. Some conditions were conducted in a closed economy, in which the pigeons earned all their daily ration of food within the session. Relative to comparable open-economy conditions, response rates in the closed economy were less affected by changes in token-production ratio, resulting in higher levels of food intake and body weight. Some of the results are consistent with the economic concept of unit price, a cost-benefit ratio comprised of responses per unit of food delivery, but most are well accounted for by a consideration of the number of responses required to produce exchange periods, without regard to the amount of reinforcement available during those exchange periods.

Key words: token reinforcement, second-order schedules, fixed-ratio schedules, unit price, key peck, pigeons

A second-order schedule of reinforcement is one in which a pattern of behavior reinforced according to one schedule is treated as a unitary response reinforced according to a second schedule (Kelleher, 1966). A type of second-order schedule is a token reinforcement schedule, in which responses produce tokens according to one schedule (the token-production schedule) and opportunities to exchange those tokens for primary reinforcement according to a second schedule (the exchange-production schedule) (Kelleher, 1958; Malagodi, 1967).

Past research has shown that token-reinforced behavior is jointly controlled by token-production and exchange-production schedule variables. Evidence of the latter comes primarily from studies in which response rates and patterns have been shown to vary systematically as a function of the schedule by which exchange periods are produced (Foster, Hackenberg, & Vaidya, 2001; Kelleher, 1958; Waddell, Leander, Webbe, & Malagodi, 1972; Webbe & Malagodi, 1978). In an experiment by Foster et al. (2001), pigeons' responses produced tokens (stimulus lights arrayed in a horizontal row above the response keys) according to a fixed-ratio (FR) 50 with exchange periods scheduled according to FR and variable-ratio (VR) schedules (i.e., when a fixed or variable number of tokens had been earned, respectively). The exchange-production ratio was varied systematically across conditions, from 1 to 8, requiring between 50 and 400 total responses per exchange. Response rates under FR exchange-production schedules varied inversely with the exchange-production FR, due mainly to increased preratio pausing and low response rates early in FR exchange cycles (the total number of responses required to produce a single exchange). Response rates were higher and preratio pauses shorter under VR than FR exchange-production schedules. Moreover, responding usually was less sensitive to changes

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in the VR exchange-production ratio than in the FR exchange-production ratio. Both of these effects are consistent with performance under simple ratio schedules, supporting the view of token reinforcement procedures as a kind of second-order schedule of reinforcement.

In comparison to research on effects of the exchange-production schedule, less is known concerning manipulations of the token-production schedule. Kelleher (1958) conducted one of the few investigations that varied the token-production schedule. In his study, chimpanzees produced tokens (poker chips) according to FR token-production schedules. With the exchange-production ratio held constant at FR 60 (i.e., 60 tokens required to produce the exchange period), the token-production ratio was increased over the course of 10 sessions from 60 to 125. Response rates were higher under the lower token-production ratio; data from the intermediate ratios were not presented. These results are generally in accord with findings from simple FR schedules, but the relatively brief exposure to each schedule and the absence of data from intermediate ratios do not permit clear conclusions.

With ratio token-production and exchange-production schedules, a potentially relevant variable emerges: the ratio of responses per unit of reinforcer, or unit price (Hursh, 1978). When the exchange-production ratio is manipulated with token-production ratio held constant, reinforcer magnitude, measured as number of reinforcers per exchange period, is equal to the exchange-production ratio. As a result, the unit price remains constant across variations in the exchange-production ratio. For example, in the Foster et al. (2001) study, with a token-production ratio of 50 and an exchange-production ratio of 2 (hereafter, FR 2 [FR 50]), 100 responses produced two tokens, each exchangeable for 2 s access to food, or 25 responses per second access to food. So, too, under the FR 8 [FR 50] condition, 400 responses produced eight tokens (16 s access to food), or 25 responses per second access to food. Based on the equivalent unit prices, one might expect response output to be roughly equal, as several studies have shown (see review by DeGrandpre, Bickel, Hughes, Layng, & Badger, 1993). Contrary to this expectation, however, response output varied substantially across conditions of equal unit price. Responding was governed not by responses per unit of food delivery (unit price) but by responses per exchange period (the exchange cycle) without regard to the number of food deliveries available per exchange period.

Another way of examining the viability of the unit price concept with token reinforcement procedures is through manipulations of the token-production ratio. Unlike exchange-production manipulations, altering the token-production ratio while holding constant the exchange-production ratio produces concomitant changes in unit price. For example, in the Kelleher (1958) study described above, with an FR 30 token-production schedule and an FR 60 exchange-production schedule, 1,800 responses produced 60 tokens, a unit price of 30. When the token-production schedule was increased to 100, while holding the exchange-production ratio constant at 60, 6,000 responses produced 60 tokens, a unit price of 100. The decrements in response rate with increases in token-production ratio are consistent with the changes in unit price.

The present study sought to explore further the effects of varying the token-production schedule and the exchange-production schedule in token-reinforcement procedures. Using a token-reinforcement schedule similar to that of Foster et al. (2001) with pigeons as subjects, FR token- and exchange-production ratios were manipulated parametrically on a within-subject basis across a wider range of schedule values than examined in prior research. The present experiment included three token-production ratios and three exchange-production ratios, and was designed to conduct most of the possible combinations. This permitted a within-subject analysis of performance in relation to the component ratios comprising these second-order token reinforcement schedules and of the relevance of the unit price concept in accounting for such performance.

The study also included a series of conditions conducted in a *closed economy*, that is, long sessions with unlimited food intake. This not only ensured that all food intake occurred during experimental sessions, but also resulted in appreciably higher levels of daily food consumption (hence, lower levels of deprivation). Performances under these conditions were compared to those under comparable conditions in a standard *open economy* with 80% body weights maintained via supplemental postsession feedings. Prior research has shown that responding under such open economies sometimes differs from that under closed economies (Hursh, 1980, 1984). For example, Zeiler (1999) showed that response rates were shallow bitonic functions of FR size in open economies but were monotonically increasing functions of FR size in closed economies. Because of the dependence of FR response output on economic conditions, and because most unit-price manipulations have been conducted in closed economies, we examined ratio schedules of token reinforcement in closed as well as open economies.

Economic issues aside, the present study sought to enhance our understanding of performance on second-order schedules of token reinforcement by providing parametric data on token-production schedules, while at the same time extending prior research on exchange-schedule effects (Foster et al., 2001; Webbe & Malagodi, 1978). The results contribute both to a parametric analysis of token production and exchange schedules across a wider range than previously examined and to an examination of the importance of economic context for token-reinforcement schedules.

METHOD

Subjects

Four male White Carneau pigeons (*Columba livia*), numbered 702, 732, 774, and 1855, served as subjects. Each pigeon had prior experience with token-reinforcement schedules. They were housed individually under a 16.5:7.5 hr light/dark cycle (lights on at 7:30 a.m., off at 12:00 a.m.). The pigeons had continuous access to water and health grit in their home cages. Pigeons were maintained at ± 20 g of their 80% free-feeding weights via supplemental postsession feeding as needed, except under closed economy conditions, when no upper weight limit was imposed.

Apparatus

Experimental sessions were conducted in an enclosure 360 mm high by 500 mm long by 360 mm wide. An intelligence panel on a wall of the enclosure was equipped with three response keys, centered vertically 115 mm from the ceiling and 90 mm from each other (center to center). Thirty-four evenly spaced, red, light-emitting diodes (LEDs) were centered 50 mm above the keys and 12.5 mm apart (center to center) and protruded 3 mm into the enclosure. The LEDs (hereafter referred to as tokens) always were illuminated in order, from left to right. The presentation and removal of tokens was controlled by an electromechanical stepping switch (Lehigh Valley Electronics®, model 1427), the operation of which also provided auditory feedback each time a token was presented or removed. Centered above the token array was a yellow houselight that provided the enclosure with diffuse illumination. When operative, side keys were illuminated green and the center key red. Pecks exceeding approximately 0.11 N to 0.14 N were counted. A hopper aperture was centered 115 mm below the left key. A solenoid-operated food hopper could be raised into this opening, allowing access to mixed grain. Food presentation was accompanied by illumination of a yellow light located inside the opening. A photo beam mounted across the aperture recorded head entry into the hopper. Continuous white noise and ventilation fans were active during experimental sessions to mask extraneous sounds. Experimental contingencies were programmed, and data collected, using a computer equipped with MED-PC® software, located in a separate room.

Procedure

Because the pigeons had previous experience with token-reinforcement schedules, no training was necessary. A session began with the illumination of a green side key (key position was counterbalanced across subjects). A fixed number of pecks on this key produced a token according to an FR schedule. Separate FR exchange schedules arranged for different numbers of tokens to produce an exchange period. Thus groups of responses were needed to produce a token and groups of tokens were needed to produce an exchange period. Exchange periods were signaled by the darkening of the green side key and the illumination of the red center key, a single response on which darkened the rightmost lit token and produced 2.5-s access to grain (timed from head entry into hopper). The exchange period remained in effect until all tokens earned during that reinforcer cycle were exchanged, followed immediately by the darkening of the red center key, the illumination of the green side key, and the beginning of the next cycle. Sessions continued until 48 tokens had been exchanged for food. (Because Pigeon 774 was consistently overweight, sessions from the final five conditions for this pigeon ended after only 32 tokens had been exchanged.)

All pigeons were exposed to a series of conditions in which both the token-production and exchange-production FR schedules were varied systematically across conditions: token-exchange FRs of 2, 4, and 8, and token-production FRs of 25, 50, and 100. (For Pigeon 1855, a mixed FR 12 FR 13 schedule, on which token production depended with equal probability on either 12 or 13 responses, was added because response rates could not be maintained reliably at the higher ratios.)

These conditions were conducted under standard deprivation conditions, in which the pigeons were maintained at approximately 80% of their free-feeding weights (i.e., in an open economy). The pigeons also underwent a series of conditions conducted in a closed economy, with sessions lasting until at least 10 min elapsed without a response. In this series of conditions, the exchange-production schedule was held constant at FR 2, whereas the token-production schedule was varied systematically across conditions. Food deliveries in the closed economy were occasionally produced without eating (i.e., the photo beam was not broken by head insertions in the hopper). The food hopper was therefore lowered either 2.5 s after head insertion (as in open-economy conditions) or after 10 s had elapsed. For some closed-economy conditions, Pigeons 702 and 1855 did not earn enough food to maintain their 80% free-feeding weights; supplementary feedings were therefore provided. In three instances, when responding had weakened to the point that sessions were not completed consistently, or 80% weight not maintained, conditions were changed in the absence of stability. Data from these conditions were omitted from analysis. Usually, however, supplementary feedings were unnecessary, as body weights in this phase were typically between 95% and 105% of free-feeding weights.

Table 1 shows the sequence of conditions and the number of sessions conducted under each. Conditions are referred to by the parameters of the token-production and exchange-production schedules. The exchange-production schedule is listed first, followed by the token-production schedule in brackets. For example, a condition with an FR 50 token production, FR 2 exchange-production would be termed FR 2 [FR 50].

Each condition lasted for a minimum of 20 sessions and until performance was deemed stable according to the following criteria: Session-wide response rates for the last five sessions of a condition were not the highest or lowest of the condition and did not show evidence of monotonically increasing or decreasing trends. The conditions reported here were parts of a more extensive investigation of token-reinforced behavior, and some intervening conditions are not reported. Due to a programming error, preratio pauses in five conditions for 2 pigeons (774 and 1855) were unavailable. Each of these conditions was later replicated following exposure to closed-economy conditions. Only data from the replications are presented for these 2 pigeons. For Pigeon 732, fewer than 7% of preratio pauses were lost; these conditions were included in the analysis, but the cycles in which measurement errors occurred were excluded.

RESULTS

All data analyses are based on the final five sessions from each condition. Figures 1 and 2 show running response rate (responses per minute exclusive of preratio pauses) and preratio pause, respectively, plotted as a function of token-production ratio (left panels) and exchange-production ratio (right panels). Different symbols demarcate the different exchange-production schedules in the left panels and different token-production schedules in the right panels. Unconnected symbols aligned vertically represent replications.

The left panels of Figure 1 show that response rates tended to decrease as the token-production ratio increased. Further, the decrements in response rate were ordered with respect to exchange-production ratio, such that rates under lower exchange-production ratios usually were less depressed than rates under higher exchange-production ra-

Table 1

Sequence of conditions for each subject and the number of sessions conducted at each (in parentheses).

Pigeon			
702	732	774	1855
Open economy		Closed economy	
FR 4 [FR 25] (48)	FR 4 [FR 25] (29)	FR 2 [FR 100] (40)	FR 2 [FR 50] (23)[a]
FR 4 [FR 50] (23)	FR 4 [FR 50] (56)	FR 2 [FR 50] (19)	FR 2 [FR 25] (28)
FR 4 [FR 100] (36)	FR 4 [FR 100] (23)	FR 2 [FR 25] (36)	FR 2 [MR 12.5] (27)
FR 2 [FR 100] (21)	FR 2 [FR 100] (53)		FR 2 [FR 50] (24)
FR 4 [FR 50] (24)	FR 8 [FR 25] (25)		
FR 8 [FR 25] (28)	FR 2 [FR 50] (22)		
FR 2 [FR 50] (27)	FR 2 [FR 25] (22)		
FR 2 [FR 25] (25)			
FR 2 [FR 100] (25)			
Closed economy		Open economy	
FR 2 [FR 100] (70)[a]	FR 2 [FR 100] (30)	FR 2 [FR 50] (24)	FR 4 [FR 50] (54)
FR 2 [FR 25] (24)	FR 2 [FR 50] (28)	FR 2 [FR 100] (24)	FR 2 [FR 50] (23)
FR 2 [FR 50] (24)	FR 2 [FR 25] (28)	FR 2 [FR 25] (22)[b]	FR 2 [FR 25] (25)
FR 2 [FR 100] (25)[a]		FR 4 [FR 25] (21)[b]	FR 2 [FR 12.5] (27)
		FR 4 [FR 50] (21)[b]	FR 4 [FR 25] (20)
		FR 4 [FR 100] (26)[b]	FR 4 [MR 12.5] (21)
		FR 8 [FR 25] (20)[b]	FR 8 [MR 12.5] (27)
Open economy			
FR 2 [FR 50] (26)	FR 2 [FR 50] (33)		
FR 4 [FR 100] (20)[a]	FR 2 [FR 25] (21)		

[a] Condition ended arbitrarily.
[b] Thirty-two reinforcers per session.

tios. The right panels of Figure 1 show this effect even more clearly. For all except Pigeon 702 under the highest token-production ratio (50), response rates varied inversely with exchange-production ratio. This effect was more pronounced under larger token-production ratios. Response rates under replications for Pigeons 702 and 732 where in some cases slightly higher than rates under original exposures, but were in accord with the original findings.

The left panels of Figure 2 show that preratio pausing varied directly with the token-production ratio. Within like token-production ratios, pausing was ordered by exchange-production ratios, such that higher exchange-production ratios produced longer pauses. This effect is more evident in the right panels, which show differential effects of token-production ratio with increases in exchange-production ratio: For each exchange-production ratio, pausing tended to vary directly with token-production ratio.

Figure 3 shows running response rates (left panels) and preratio pausing (right panels) across successive token-production segments under all combinations of token-production and exchange-production schedules. A token segment is defined as the portion of an exchange cycle that occurs during the production of a given token. Response rates usually were lower in the earlier than in the later segments, which were closer to the exchange period and food. Under the higher exchange-production ratios, rates increased in graded fashion across segments. The rate increases were a negatively accelerated function of segment position. Under the FR 4 exchange-production schedule, the schedule under which all token-production ratios were examined across a sufficient range of segments, the slopes of the functions usually were higher at the higher token-production ratios.

Preratio pausing (right panels) was longest in the initial segment, and relatively short and undifferentiated thereafter. Within a given exchange-production ratio, initial-link pausing varied directly with the token-production ratio. Increasing the exchange-production ratio from 2 to 4 also increased initial-link pauses, but usually only at the highest token-production ratio.

Figure 4 shows running rates (left panels) and total responses (right panels) as a function

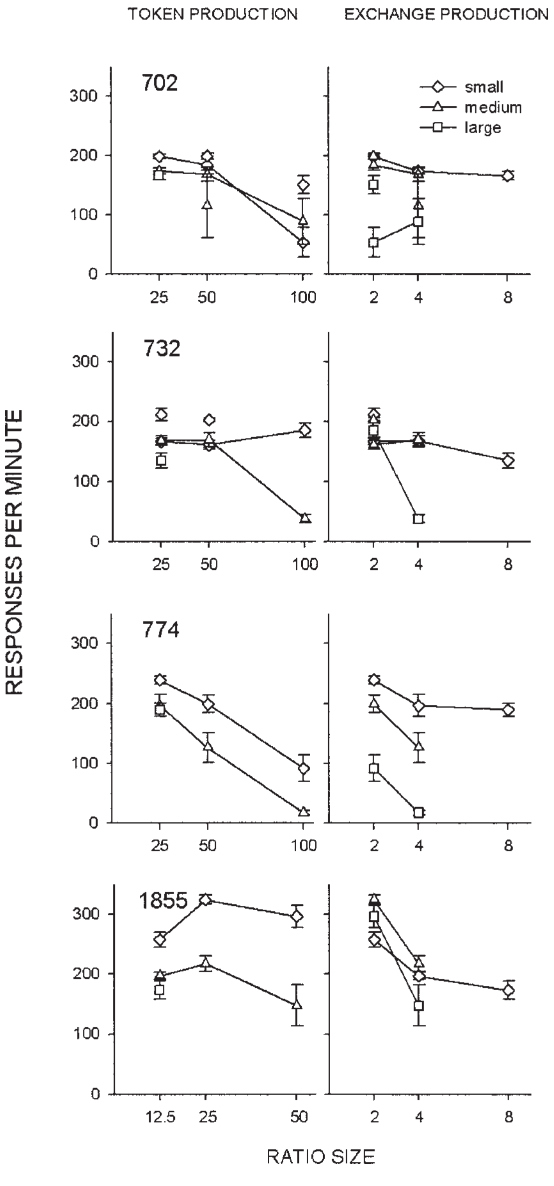

Fig. 1. Mean running responses per minute (exclusive of preratio pauses) and standard deviations plotted as a function of token-production ratio (left panels) and exchange-production ratio (right panels) for each pigeon in the final five sessions of each condition. Unconnected points represent data from replicated conditions. The different symbols represent different ratio sizes (small, medium, large) for the exchange-production ratio (left panels) and token-production ratio (right panels).

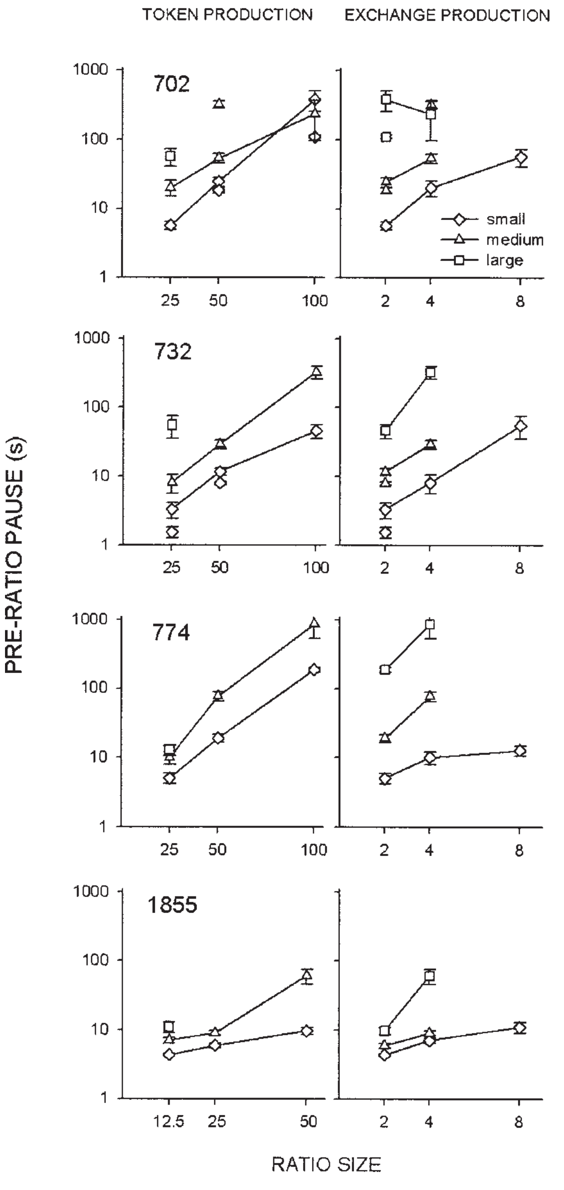

Fig. 2. Mean preratio pausing and standard deviations plotted as a function of token-production ratio (left panels) and token-exchange ratio (right panels) for each pigeon in the final five sessions of each condition. Unconnected points represent data from replicated conditions. Note logarithmic *y* axis. The different symbols represent different ratio sizes (small, medium, large) for the exchange-production ratio (left panels) and token-production ratio (right panels).

of token-production ratio under the closed economy (filled symbols), along with the comparable data from the open economy (open symbols). Because closed economy conditions were all run under an FR 2 exchange-production schedule, only the open-economy conditions with FR 2 exchange-production schedule are included. Response rates were consistently higher in the open economy than in comparable closed-

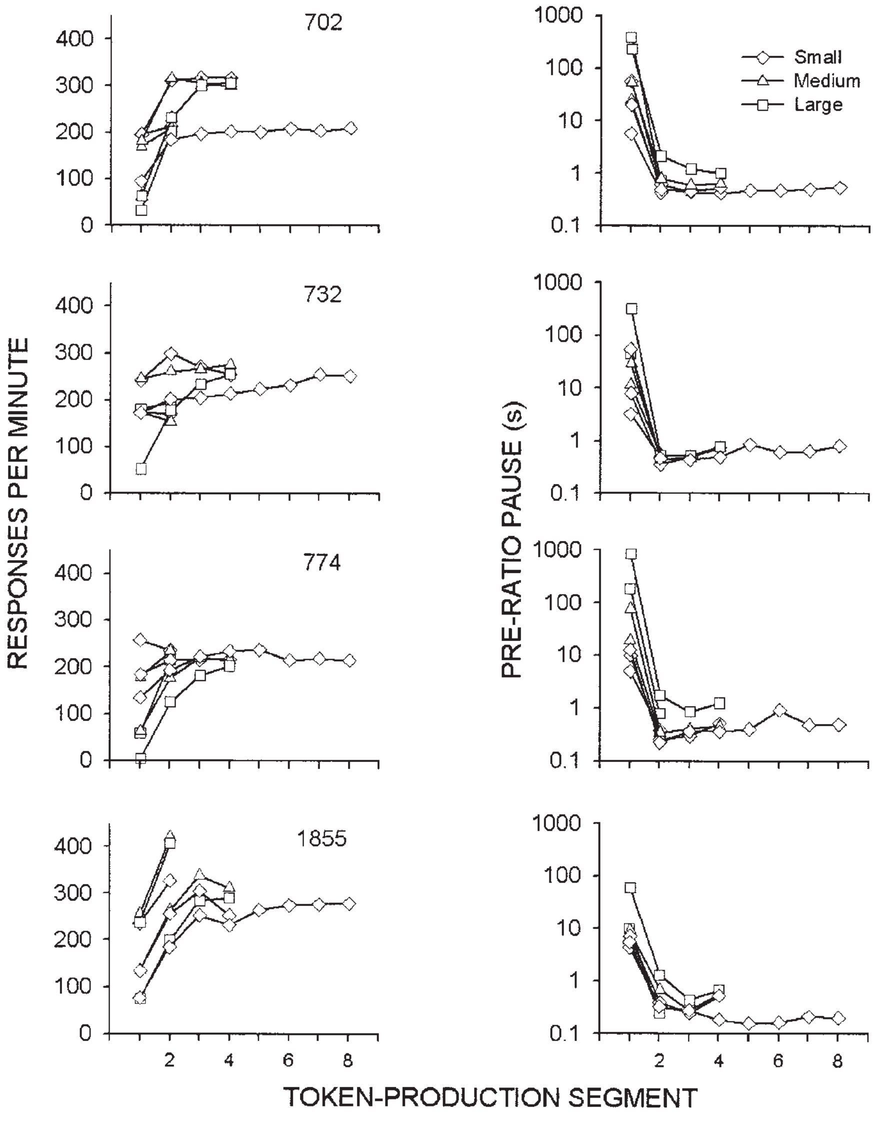

Fig. 3. Mean running responses per minute (left panels) and preratio pausing (right panels) under each token-production ratio (FR 25, 50, or 100) plotted as a function of token-production segment for each pigeon in the final five sessions of each condition. Note logarithmic *y* axis on right panels. The different symbols represent different ratio sizes (small, medium, large) for the token-production ratio.

economy conditions. The general lack of variation in the closed-economy response rates translated to higher levels of overall response output (right panels), also plotted as a function of token-production ratio. Because all subjects completed sessions in the open economy, response output necessarily increased proportionately with increasing token-production ratio. The function obtained in the closed economy was displaced upward but roughly parallel to that obtained in the open economy.

Figure 5 shows mean obtained food deliveries (top panel) and mean presession body weights (bottom panel) plotted as a function of token-production ratio under the closed economy. Broken horizontal lines depict the number of food reinforcers (top) or 80% body weights (bottom) from the open economy. All

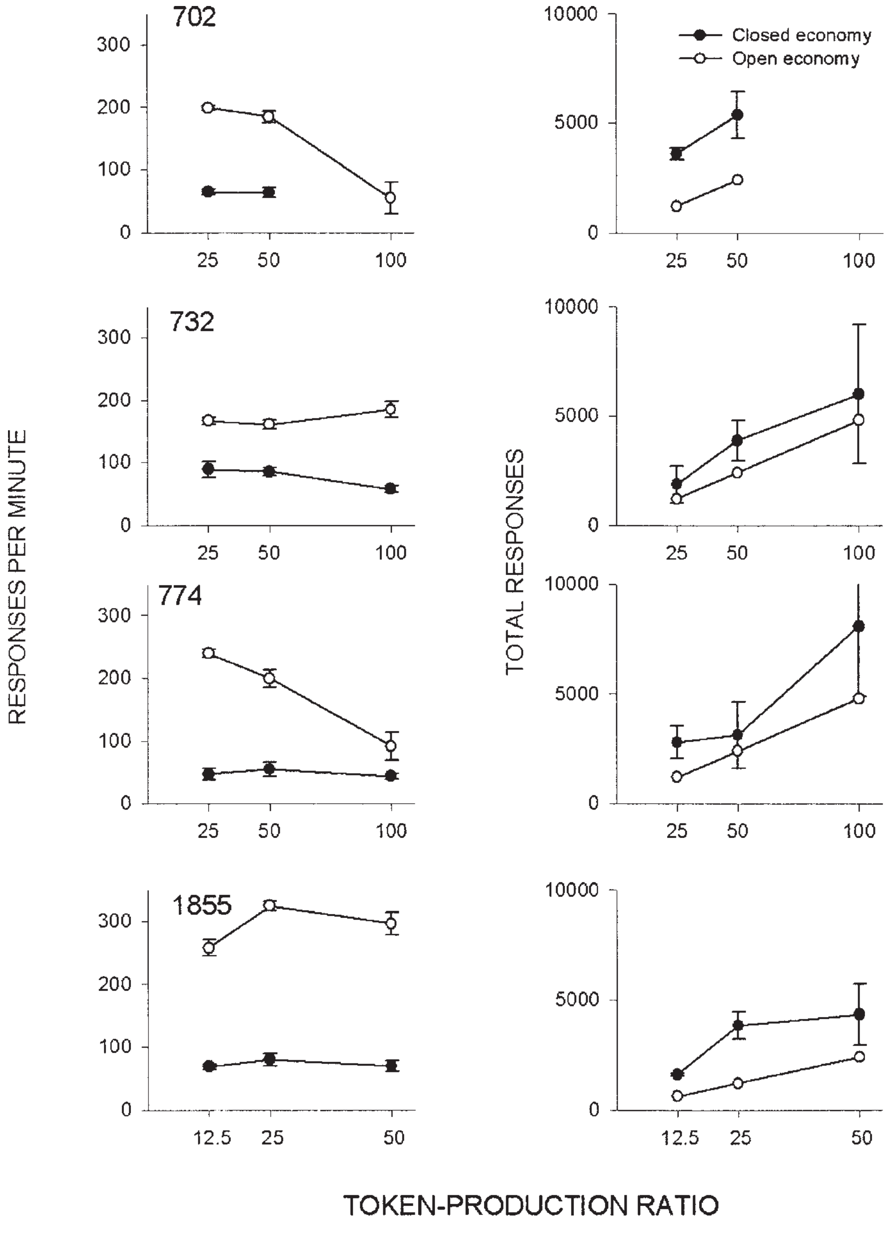

Fig. 4. Running response rate (left panels) and total responses (right panels) plotted as a function of token-production ratio (FR 25, 50, or 100) under closed economy (filled symbols) and open economy (open symbols) for each pigeon in the final five sessions of each condition. Error bars represent standard deviations.

pigeons produced more reinforcers under the closed economy than under the open economy. Consumption decreased with increases in the token-production ratio for some pigeons, but had little effect on presession body weights (bottom). Body weights were maintained at between 95% and 105% of free-feeding weight throughout the closed-economy conditions.

DISCUSSION

The present study gathered parametric data on responding under various combinations of ratio-based token reinforcement schedules. Overall, responding varied inversely with the token-production and exchange-production ratios (Figure 1), due mainly to long pauses and low response rates in early token-pro-

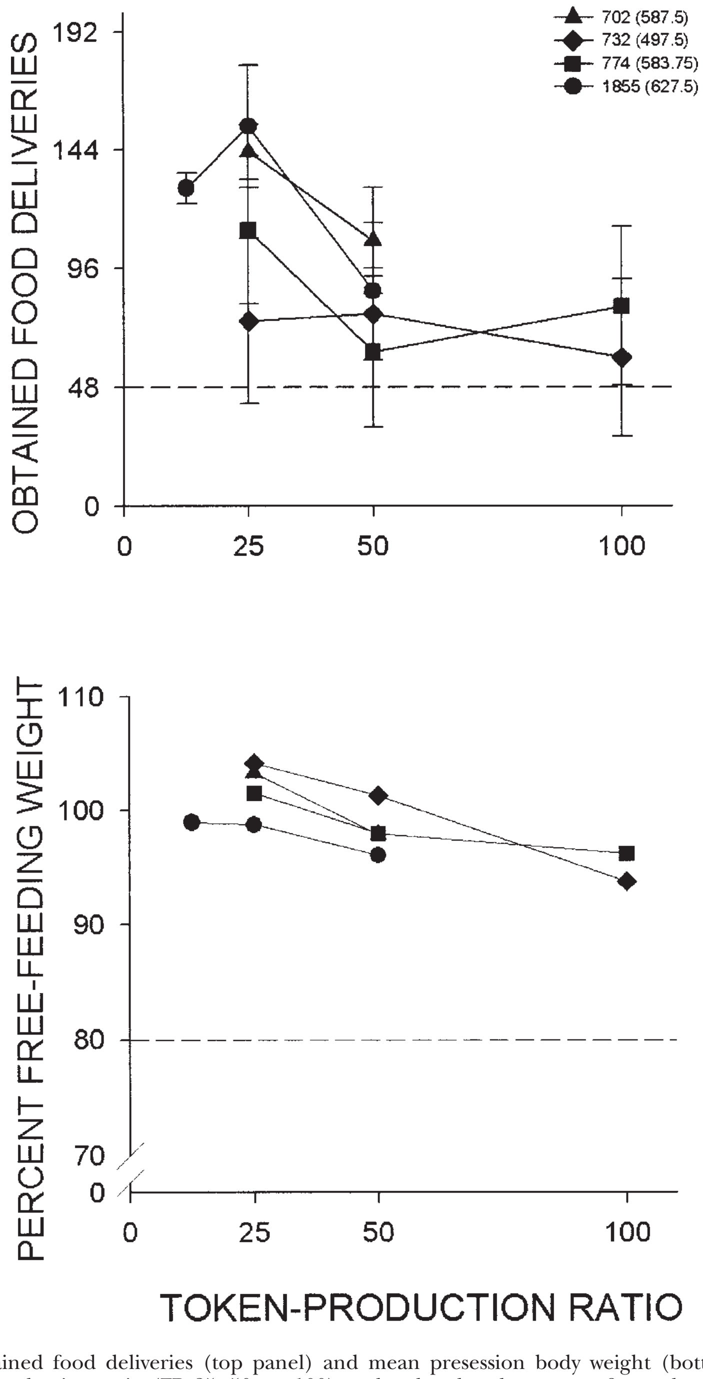

Fig. 5. Mean obtained food deliveries (top panel) and mean presession body weight (bottom panel) plotted as a function of token-production ratio (FR 25, 50, or 100) under the closed economy for each pigeon in the final five sessions of each condition. The different symbols correspond to different pigeons, whose free-feeding weights (in grams) are shown in parentheses. Error bars in the top panel are standard deviations.

duction segments (Figure 3). Response rates increased and pausing decreased with proximity to exchange periods and food.

Token-production manipulations (Figure 1) had effects similar to those found by Kelleher (1958), in that responding varied inversely with token-production ratio. In the present study, however, the ratios were varied across a wider range of steady-state conditions. Within a token-production ratio, response rates usually were ordered with respect to exchange-production ratio. These results extend previous research concerning token-reinforcement schedules by showing the generality of the effects of token-production manipulations across a range of exchange-production ratios.

Similarly, exchange-production manipulations (Figure 1) produced results consistent with prior research. The inverse relation between response rate and exchange-production ratio is in general agreement with the findings of Foster et al. (2001) over a similar range of exchange-production ratios. This relation was most pronounced at the larger token-production ratios. In combinations that included the lowest token-production ratio, response rates varied much less (if at all) with the exchange-production ratio. As shown in Figure 1 (right panels), the functions relating response rates to exchange-production ratio typically were ordered with respect to token-production ratio. This finding extends prior research by showing that the effects of exchange-production ratio depend on the token-production ratio.

The results have implications for the unit-price concept. Using response rate as a measure of response output (see Sumpter, Temple, & Foster, 1999), the relatively flat functions seen at some of the smaller token-production ratios (right panels of Figure 1), are consistent with the prediction of the unit-price formulation that schedules with the same cost/benefit ratio should engender equal response output. At higher token-production ratios, however, the functions tended to decrease as exchange-production ratio increased, a result that deviates from a strict reading of the unit-price formulation. These results follow from a consideration of the number of responses to produce an exchange period, without regard to the amount of food (number of reinforcers) available within the exchange period. The effects of the token-production ratio (left panels of Figure 1) were broadly consistent with unit price. When reinforcer magnitude (the denominator in the unit-price equation) remains constant, however, changes in unit price are determined entirely by ratio size (the numerator in the unit price equation). Such results, while broadly consistent with unit price, are not uniquely so; they also agree with prior research on fixed-ratio performance, both in simple and second-order and chained-ratio schedules (Jwaideh, 1973; Kelleher, 1958; Mazur, 1983).

The decreasing or mildly bitonic functions seen under token-production manipulations are in general agreement with those reported for simple ratio schedules in open economies (Mazur, 1983), but differ from those reported for closed economies (Zeiler, 1999). In a closed economy, response rates generally increase with ratio size (Hall & Lattal, 1990; Zeiler, 1999; but see Timberlake & Peden, 1987). In Zeiler's comparisons of pigeons' schedule-controlled performances in open and closed economies, the open-economy sessions consisted of a fixed number of food deliveries (30) and food deprivation (80% of their free-feeding weights via supplementary feedings), whereas the closed-economy sessions lasted 24 hr and permitted unlimited food consumption. Upon completing the schedule requirement under the closed economy, a separate food key was illuminated, pecks on which produced 3-s hopper cycles, with the food key remaining active until 30 s elapsed without a response. Response rates increased as a function of FR in the closed economy but were mildly bitonic in the open economy. Further, responding could be maintained at far more stringent schedule requirements under the closed than under the open economy.

When analyzed in unit-price terms, the consumption and response-output functions in the closed economy were only partially consistent with prior results. The typical functions relating consumption and response output to unit price are decreasing and bitonic, respectively (DeGrandpre et al., 1993). As Figure 4 (right panels) and Figure 5 (top panels) show, total responding increased, while consumption remained constant or slightly decreased, as unit price increased. This deviation from previous results is likely due to the restricted range of unit prices, which fell on the inelastic portion of the demand curve. Even at the highest prices, food consumption and body weights exceeded those under the open economy (Figure 5). Had we included some higher unit prices we might have produced the more typical demand functions, characterized by mixed elasticity (Hursh, 1978, 1980, 1984).

Economic models of response output generally are not formulated at the level of response patterning. In the present experiment, local patterns of behavior within an exchange-production cycle changed with proximity to the exchange period (Figure 3). These effects were largely a result of longer preratio pausing and weak behavior early in the ratio. Even with pausing excluded, response rates increased with proximity to exchange periods and food. In most conditions, especially at the lower token-production and exchange-production ratios, response rates were bivalued: low in the initial segment and high thereafter. At the higher token-production and exchange-production ratios, the functions were more graded: low in the initial link and steadily increasing across token-production segments leading to exchange periods and food (see Figure 3).

These within-cycle effects correspond with those reported under extended chained schedules with FR components. Jwaidah (1973) exposed pigeons to extended (3- and 5-link) chained FR schedules along with comparable tandem schedules with response requirements matched to those of the chained schedules. Ratio requirements per link were varied from 3 to 48 across conditions. Preratio pause durations and ratio-completion times varied directly with ratio size and number of links in the chain, a finding that corresponds to the present results. When compared to equivalent tandem schedules, chained-schedule responding was characterized by longer preratio pauses and ratio-completion times in the early segments. Although the present study did not include tandem control conditions, the graded pattern of responding seen under higher token- and exchange-production FR combinations (Figure 3) resemble patterns seen in Jwaideh's chained-schedule conditions.

Such correspondence is perhaps not surprising given the formal similarities of token reinforcement and extended chained schedules. In both schedule types, a distinct stimulus change delineates the completion of each segment; but unlike second-order schedules of brief-stimulus presentation, such segment-correlated stimuli remain present in chained schedules, providing a continuous marker of temporal proximity to food. The main difference between extended chained and token schedules is with the number of reinforcers per cycle. Chained schedules provide just one reinforcer per cycle whereas on token schedules the number of reinforcers depends on the number of completed segments. Given the relatively small effects of number of reinforcers per cycle on response output shown in Figure 1, one might expect chained and token schedules to be even more similar. Future research should explore more precisely the functions of stimuli embedded within chained and token schedules.

In summary, the present research replicates and extends the results of previous token-reinforcement studies (Foster et. al., 2001; Kelleher, 1958), and does so in a way that bears on an economic analysis. The overall pattern of results is not well accounted for by a literal interpretation of unit price. Only in conditions where unit price was driven by changes in ratio requirements are results consistent with a unit-price account. Perhaps it is possible to reconcile the present results with a modified version of the unit price model that differentially weights the separate components of the equation (Foster & Hackenberg, 2004; Madden, Bickel, & Jacobs, 2000; Madden, Dake, Mauel, & Rowe, 2005), but this would come at the expense of the simple elegance of the unit-price concept, a distinctive feature of which lies in the functional equivalence of costs (response requirements, reinforcer delay) and benefits (reinforcer magnitude). However such matters are resolved, it should be increasingly clear that economic models that ignore local schedule variables are bound to be incomplete.

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