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# *Allocation of time and human energy and its effects on productivity*

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## I. INTRODUCTION

The supply of effort on the job has been virtually ignored as a component of the effective supply of labour. Typically, labour supply models assume the worker chooses the utility-maximizing number of hours to supply on the job as a function of a fixed wage rate which is independent of the worker's effort. This paper generalizes the worker's choice problem to include the situation in which the worker's income depends on effort exerted on the job as well as time spent on the job.

In order to analyse the problem it is necessary to measure effort. How hard an individual works is determined by a combination of psychological and physical factors. While the psychological factors are difficult to quantify, one element in the physical component can be measured. The level of caloric intake determines a constraint on the level of energy that can be exerted by an individual. Thus the total level of energy chosen and the allocation of this energy between market and nonmarket activities constrains the amount of energy that can be exerted on the job.

A model is developed in which utility depends on goods, leisure time, calories, and household responsibilities, where calories provide a proxy for the intensity of effort. The worker's objective is to maximize his utility by choosing quantities of goods, leisure time, calories, and a level of household responsibilities, subject to a budget constraint. Labour income is the product of labour time and the effective hourly wage. The effective wage rate is determined by a production function which relates individual output to individual characteristics and energy exerted on the job. Energy exerted on the job is calculated as the difference between the total quantity of available energy and the energy expended performing the chosen level of off-the-job activities.

The manner in which the level of caloric intake determines a constraint on the level of energy that can be expended by the body can be understood by examining the process through which the body converts food into energy (Davidson *et al.* 1975). Energy is defined as the capacity to do work or to produce a change in matter. Chemical energy in the form of food is ingested by the human organism and transformed, through the process of metabolism, into mechanical energy to perform work, into other forms of chemical energy which are used for bodily maintenance,

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into electrical energy for brain and nerve activity, or released as a by-product of metabolism in the form of thermal energy, which also maintains body temperature.

The basic unit used to express energy in the area of nutrition is the calorie. The calorie represents thermal energy and can be equated to mechanical and chemical energy. Thus we can define an individual's capacity to do productive work in terms of calories.

The energy requirements of the body take precedence over all other needs. The main factors that determine the total energy requirements of an adult are the basal metabolic rate (BMR) and the level of physical activity. The BMR is the minimal amount of energy needed by the body at rest in a fasting state, and can be determined by the height, weight, sex and age of an individual. After calculating the daily BMR, the caloric requirements for activity levels above the BMR can be determined.

Once a person's ideal body weight has been determined, the amount of energy required to maintain that weight (given a level of activity) can be determined. If an individual's diet provides calories in excess of the recommended amount, obesity can be avoided only by increased activity. If the diet provides fewer calories than required at a given energy level, the body will adjust by reducing weight and/or decreasing voluntary activity. Thus, the number of calories chosen, and the allocation of energy over the work week and between on and off-the-job activities, determines a constraint on the energy that can be supplied on the job. For example, consider two individuals, both with ideal weight that can be maintained on a diet averaging 2000 calories per day. This means that both individuals will maintain a stable weight with an average caloric intake of 14 000 calories per week. There is a number of ways of allocating 14 000 calories. The first individual may prefer a steady supply of energy, choosing a diet of 2000 calories per day. The second individual may enjoy pizza and beer in front of the television set on weekends, and choose a diet of 4000 calories per day on Saturday and Sunday, and 1200 calories per day from Monday to Friday. Both individuals will maintain successfully a stable weight (assuming, of course, that average energy expenditure is consistent with energy consumption). However, since it is the total number of calories consumed in the previous twenty-four hour period that is most relevant in determining energy available for performing productive activities during a given period, we would expect the individual that consumes the greater number of calories during the work week to be more productive on the job.

The model yields a number of predictions whose validity depend on the particular specification of the production function. Thus, the objective is twofold: first, to establish the purely technological production function which relates energy expended on the job and individual characteristics to individual output; second, using the results from the estimation of the production function, to estimate demand equations for leisure, calories and household responsibilities, and use the results to verify the predictions of demand theory.

In order to estimate the desired equations, an original data set was generated by the researcher. An industry in which the workers were paid on a piece rate basis was chosen. There were two reasons for choosing piece rate workers. The workers were free to choose both their supply of labour time and their intensity of effort on the job. The piece rate method of compensation also provides a fairly unambiguous measure of individual productivity. Data were collected on labour supply, individual diet, household responsibilities, and individual output, as well as other socioeconomic and demographic variables.

The results of the estimation of the production function indicate that the quantity of available energy and years of worker experience are positively related to output, that greater household responsibilities and age are negatively related to output, and that schooling is not a significant factor in determining output.

Contrary to other studies which used the work week as the measure of the supply of labour time, the wage elasticities derived in this study are positive. It is generally not clear if the work week reflects individual or employer preferences. Since the workers were free to take breaks whenever they wished, the supply of labour time observed per day is extremely sensitive to workers' preferences. It is thus felt that this is a truer measure of the wage elasticity. It is also found that an increase in the cost per calorie reduces the demand for calories and also reduces both labour time supplied and household responsibilities, since leisure time and lower household responsibilities are less energy demanding.

The paper is organized as follows: Section II presents the model. Section III describes the survey. The production is derived and the results of its estimation are presented in Section IV. The results of the estimation of the demand equations are presented in Section V. Section VI provides some concluding remarks.

## II. THE MODEL

The individual is faced with the problem of maximizing utility subject to a budget constraint. However, in this case the worker is free to choose more than just quantities of goods and leisure time. The worker also chooses the total quantity of energy to provide to his body and the level of energy to exert off the job. These choices in turn affect the budget constraint through the production function which relates energy expended on the job and individual characteristics to individual output. Since workers are paid per unit of output, an individual's labour income is the product of the piece rate per unit and the number of units produced by that individual.

Formally, each worker faces the following optimization problem:

$$\max_{\mathbf{X}, L, K, H} U(\mathbf{X}, L, K, H)$$

$$\text{s.t. } \mathbf{p}\mathbf{X} + rK = qz(24 - L) + V \quad (1)$$

$$z = f(EJ, I) \quad (2)$$

$$EJ = \alpha(K - E(H)) \quad (3)$$

The vector **X** represents quantities of nonenergy-producing market goods. The total quantity of time spent either not at the work site or at the work site but on break is denoted by $L$. The twenty-four hour day is thus divided into time spent working $(24 - L)$ or time spent not working $(L)$. The term $K$ represents the total number of calories available from the diet. The level of energy expenditure off the job is represented by the scalar $H$. The value of $H$ is positively related to the level of household responsibilities. The vector **p** and the scalar $r$ are the prices of goods and calories respectively. The scalar $q$ is the piece rate per unit output. The value of $z$ is the number of units of output produced per hour. The scalar $V$ is the quantity of any other nonlabour income. The production function $f$ relates energy available on the job, $EJ$, and individual characteristics, $I$ to the production of output. Energy available on the job is determined by total energy, $K$, and energy required to perform activity level $H$ off the job, weighted by $\alpha$ to account for differences in individual energy requirements. The caloric requirement for performing activity level $H$ is expected to increase as H increases. Total available energy is expended either off the job $(E(H))$ or on the job $(K-E(H))$.

Substituting Equation 3 into 2 yields

$$z=f(\alpha(K-E(H)),I)$$

Let $F(C,H,I)=f(\alpha(K-E(H)),I)$. $C$ denotes available energy relative to individual energy requirements. This can be substituted into Equation 1 to yield the following constrained maximization problem:

$$\max_{\mathbf{X},L,K,H} U(\mathbf{X},L,K,H)$$
$$\text{s.t. } \mathbf{p}\mathbf{X}+rK=q(24-L)\mathrm{F}(C,H,I)+V$$

The first order conditions for utility maximization are

$$U_1-\lambda p=0$$
$$U_2-\lambda qF=0$$
$$U_3-\lambda\{r-q(24-L)F_1\}=0$$
$$U_4+\lambda(24-L)qF_2=0$$
$$\mathbf{p}\mathbf{X}+rK-q(24-L)F-V=0$$

Notice that the implicit marginal cost of expending energy level $H$ off the job is $qF_2$.

Using the second order conditions implied by the maximization, the problem can be formulated in matrix notation as:

$$\begin{bmatrix} U_{11} & U_{12} & U_{13} & U_{14} & -p \\ U_{21} & U_{22} & U_{23}-\lambda qF_1 & U_{24}-\lambda qF_2 & -qF \\ U_{31} & U_{32}-\lambda qF_1 & U_{33}+\lambda q(24-L)F_{11} & U_{34}+\lambda q(24-L)F_{12} & -\{r-q(24-L)F_1\} \\ U_{41} & U_{42}-\lambda qF_2 & U_{43}+\lambda q(24-L)F_{21} & U_{44}+\lambda q(24-L)F_{22} & q(24-L)F_2 \\ \mathbf{p} & qF & \{r-q(24-L)F_1\} & 0 & 0 \end{bmatrix} \begin{bmatrix} d\mathbf{X} \\ dL \\ dK \\ dH \\ d\lambda \end{bmatrix}$$

$$= \begin{bmatrix} \lambda & 0 & 0 & 0 & 0 \\ 0 & \lambda F & 0 & 0 & 0 \\ 0 & -\lambda(24-L)F_1 & \lambda & 0 & 0 \\ 0 & -\lambda(24-L)F_2 & 0 & -\lambda(24-L) & 0 \\ -\mathbf{X} & -(24-L)F & -K & 0 & 1 \end{bmatrix} \begin{bmatrix} d\mathbf{p} \\ dq \\ dr \\ d(qF_2) \\ dV \end{bmatrix}$$

The expression on the left hand side of the equality represents the terms of the second partials of the lagrangian function $L=U(\mathbf{X},L,K,H)-\lambda\{\mathbf{p}\mathbf{X}+rK-q(24-L)F-V\}$ which are associated with changes in the choice variables $\mathbf{X}$, $L$, $K$, and $H$. The right hand side is composed of the terms of the lagrangian function which are associated with changes in the parameters $\mathbf{p}$, $q$, $r$, and $qF_2$. Let $A$ and $B$ denote, respectively, the left hand side and right hand side coefficient matrices. The partical derivatives of X, $L$, $K$, and $H$ with respect to each of the parameters **p**, $q$, $r$ and $qF_2$ can be found by solving for the terms of the matrix $A^{-1}B$. Let $a_{ij}$ represent the $(i, j)$ term of $A^{-1}$. The following partial derivatives represent the terms of the matrix $A^{-1}B$:

$$\partial X/\partial \mathbf{p} = \lambda a_{11} - Xa_{15} \quad (4)$$

$$\partial X/\partial q = \lambda F a_{12} - \lambda(24-L)F_1 a_{13} - \lambda(24-L)F_2 a_{14} - (24-L)Fa_{15} \quad (5)$$

$$\partial X/\partial r = \lambda a_{13} - Ka_{15} \quad (6)$$

$$\partial X/\partial(qF_2) = -\lambda(24-L)a_{14} \quad (7)$$

$$\partial X/\partial V = a_{15} \quad (8)$$

$$\partial L/\partial \mathbf{p} = \lambda a_{21} - Xa_{25} \quad (9)$$

$$\partial L/\partial q = \lambda F a_{22} - \lambda(24-L)F_1 a_{23} - \lambda(24-L)F_2 a_{24} - (24-L)Fa_{25} \quad (10)$$

$$\partial L/\partial r = \lambda a_{23} - Ka_{25} \quad (11)$$

$$\partial L/(qF_2) = -\lambda(24-L)a_{24} \quad (12)$$

$$\partial L/\partial V = a_{25} \quad (13)$$

$$\partial K/\partial \mathbf{p} = \lambda a_{31} - Xa_{35} \quad (14)$$

$$\partial K/\partial q = \lambda F a_{32} - \lambda(24-L)F_1 a_{33} - \lambda(24-L)F_2 a_{34} - (24-L)Fa_{35} \quad (15)$$

$$\partial K/\partial r = \lambda a_{33} - Ka_{35} \quad (16)$$

$$\partial K/\partial(qF_2) = -\lambda(24-L)a_{34} \quad (17)$$

$$\partial K/\partial V = a_{35} \quad (18)$$

$$\partial H/\partial \mathbf{p} = \lambda a_{41} - Xa_{45} \quad (19)$$

$$\partial H/\partial q = \lambda F a_{42} - \lambda(24-L)F_1 a_{43} - \lambda(24-L)F_2 a_{44} - (24-L)Fa_{45} \quad (20)$$

$$\partial H/\partial r = \lambda a_{43} - Ka_{45} \quad (21)$$

$$\partial H/\partial(qF_2) = -\lambda(24-L)a_{44} \quad (22)$$

$$\partial H/\partial V = a_{45} \quad (23)$$

These terms are analogous to the Slutsky decomposition of the response of a utility-maximizing consumer to a change in price. For instance, in the first equation, the first term on the right hand side represents the pure substitution effect of a change in the price of consumption goods, and the second term represents the income effect of a change in the price of consumption goods. However, examination of the seventh equation (Equation 10) illuminates striking differences between this model and the typical formulation. The seventh equation (Equation 10) represents the labour supply response of a utility-maximizing worker to changes in the piece (wage) rate. The income term is represented by $(24-L)Fa_{25} = (24-L)F\partial L/\partial V$. However, the substitution term has three components, each depending on the particular technological production function. While the negative semidefinite properties of the matrix $A^{-1}$ imply that the first of these three substitution terms is negative, the other terms are unsigned. Thus, when the piece rate wage increases, the demand for leisure can increase or decrease, depending on the size of the income effect and on the production function $F$.

By solving for the terms $a_{ij}$ and using the negative semidefinite properties of the matrix $A^{-1}$, a set of refutable hypotheses involving the estimated parameters of the demand equations and the production function can be established. The details are presented in the Appendix.

Since the specific form of the production function $F$ is required in order to estimate the demand equations, the production function has been estimated and the results are presented in Section IV. The demand equations are estimated in Section V.

## III. THE SURVEY

The previous section presents a model in which workers maximize a utility function of goods, leisure time, energy and household responsibilities, subject to a budget constraint which depends on the energy supplied on the job and on individual characteristics. Estimation of the demand equations requires establishing the technological production function which relates energy supplied on the job and individual characteristics to quantity of output produced.

To identify the technological production function, it was necessary to use data from a production process in which each individual's output is readily identifiable. Production processes in which workers are paid per piece for their output are ideal, since records are kept of individual output. Energy expenditure on the job can be determined if the quantity of total available energy and energy requirements off the job are known. Thus, the information needed to establish the production function is quantity of individual output, total available energy, energy requirements off the job, and individual productivity-related characteristics such as experience, education and age. The additional information needed to estimate the demand equations include hours of labour time supplied, total calories consumed and cost per calorie, household responsibilities, and other socioeconomic and demographic characteristics. Since no existing data sets provide the required information, it was necessary to generate an original data set with dietary information and output per worker, as well as other individual characteristics.

The sample consisted of 135 workers in a clothing factory in Rochester, New York.[1] The factory specialized in the production of men's suits. All workers in the sample were paid on a piece rate basis. The workers were divided between three jobs: hand tailors, pressers and pattern cutters. Workers were relatively free to move between jobs according to their preferences, by filing a request for a job change with the union representative. Job changes were generally granted within one month. All workers in the sample expressed satisfaction with their current position. Personal interviews were conducted at the work site. The workers were informed that the survey was being conducted privately by a student and that all responses were confidential. Each interview lasted about thirty minutes.

Each worker was requested to provide information about his education, work experience and habits, and average hourly piece rate wage; about marital status and children, total household income, and off-the-job activities; and about health and dietary habits. All workers were required to spend eight hours per day at the work site. Because of the piece rate nature of compensation, workers were permitted to take breaks whenever they wished. Since workers were not permitted to work more than eight hours per day, nor to leave the work site early, it is possible that this constraint affected individual behaviour. For instance, workers could opt for greater intensity of effort and a longer break, but the option of a more leisurely pace and extra

[1]See Hersch (1981) for a complete description of the sample and survey methodology.

hours on the job was unavilable, as was the option of greater intensity of effort and an early quitting time. Investigation of the relationship between the time spent on break and the preferred length of work week indicated that individuals who claimed they preferred a shorter work week spent more time on break. Sixty-three per cent of the workers expressed a preference for a forty hour work week, while only three of the workers preferred a work week in excess of forty hours. It is thus felt that the flexibility provided by breaks permitted optimizing behaviour in most cases with respect to choice of work time.

A constant rate per piece was paid, irrespective of the number of units produced or individual earnings. In the case where earnings fell below the legal minimum wage (of $3.10 per hour), the worker received the minimum wage. This study uses actual peice-rate earnings which were confirmed by factory records.

Recording and evaluation of the dietary intake of an individual is the most difficult aspect of nutritional assessment, since it is difficult to record a person's food intake without influencing it. Two methods are used for assessing individual dietary intake (Krause and Mahan, 1979). The most popular is the 24-hour recall method, in which the individual is asked to recall all food and drink consumed in the previous twenty-four hour period. The second method required that the individual keep a food diary, which introduces a bias if the individual modifies his diet in response to what he believes the researcher wants to hear. The 24-hour recall method has been found to be fairly reliable and has been used in several large food consumption surveys, including the Food Consumption Survey of 1965 and the Health and Nutrition Examination Survey (HANES) of 1971–1974. The 24-hour recall method was also used in this study. Food values were tabulated using Pennington and Church (1980). Interviews were conducted from Tuesday to Friday so that only work week diets were recorded. Workers whose previous day's intake was not typical of their usual intake were not included in the estimations.

There were 68 men and 67 women in the sample. Eighty workers were employed as hand tailors, twenty-one were pressers and thirty-four were pattern cutters. Table 1 reports sample means and standard deviations for some of the variables.

## IV. THE PRODUCTION FUNCTION

In order to estimate the demand equations, the specific form of the tehcnological production function $F$ which relates energy expended on the job and individual characteristics to individual output is required. The form of the production function and the results of its estimation will be presented in this section.

We wish to estimate the parameters of the production function $F$, where

$$z = F(C, H, \mathbf{I}).$$

The value of $z$ is the number of units of output produced per hour, $C$ represents total available energy measured in calories, $H$ is a measure of household responsibilities, and $\mathbf{I}$ is a vector of individual characteristics which are related to worker productivity. The precise definitions of the variables used for estimation are discussed in the following paragraphs.

By normalizing the piece rate per unit of output as 1, the average piece rate wage per hour

Table 1. *Sample means and standard deviations*

| | |
|---|---|
| Years of experience | 21.5 (11.5) |
| Years of schooling | 9.4 (3.0) |
| Age | 48.0 (11.4) |
| Marital status: | |
| Married | 80.0% |
| Single | 6·7% |
| Divorced or Widowed | 13.3% |
| Average hourly piece rate wage | $6.51 (1.06) |
| Total household income in 1979 | $18656.30 (7836.40) |
| Other nonlabour income | $6015.1 (7227.70) |
| Number of children aged 13–18 | 0.32 (0.64) |
| Number of children aged 6–12 | 0.27 (0.59) |
| Number of children under 6 years old | 0.17 (0.50) |
| Number of breaks from work per work day | 2.14 (1.71) |
| Time spent on breaks per day in minutes | 25.2 (21.8) |
| Calories per work day | 1751.5 (598.6) |
| Basal metabolic rate | 1509.5 (193.6) |
| Household responsibilities (ranging from 1 = minimal to 5 = extensive) | 2.5 (1.5) |

Note: Standard deviations are reported in parentheses.

worked can be used as the measure of individual output. That is,

$$z = \frac{8 \text{ hours} \times \text{average hourly piece rate wage}}{8 \text{ hours} - \text{time spent on break}}.$$

The length of the standard work day was eight hours.

The main factors that determine the total energy requirements of an adult are the basal metabolic rate (BMR) and the level of physical activity. The BMR is the minimum amount of energy needed by the body at rest in a fasting state, and is determined by the height, weight, sex and age of individual. Total caloric intake must be adjusted by individual BMR to provide a measure of the quantity of energy available for expenditure on physical activities. Thus the measure of available energy used in estimating the production function[2] is

$$C = \frac{\text{Total calories consumed per work day}}{\text{Basal metabolic rate}}.$$

The value of $H$ ranges from one to five, where one represents minimal household responsibilities and five represents extensive household responsibilities.

The individual characteristics which may be related to individual productivity are age, experience and education. The value of experience used is the number of years in the garment industry, and education is measured by the number of completed years of formal schooling.

[2]Other specifications of available energy were used with no appreciable difference in results.

The following Cobb–Douglas production function was estimated[3] with the results reported in Table 2.

$$\ln z = a_0 + a_1 \ln C + a_2 \ln H + a_3 \ln age + a_4 \ln exper + a_5 \ln school$$

Table 2. *Regression coefficients for variables in production function*

| Variable | Coefficient |
|---|---|
| $\ln C$ | 0.222[a] |
| | (4.21) |
| $\ln H$ | −0.134[a] |
| | (3.89) |
| $\ln age$ | −0.411[a] |
| | (4.15) |
| $\ln exper$ | 0.164[a] |
| | (4.49) |
| $\ln school$ | 0.0063 |
| | (0.17) |
| Average $\ln z$ | 1.894 |
| Constant | 3.068 |
| $R^2$ | 0.42 |
| Number of observations | 135 |

Estimated equation: $\ln z = a_0 + a_1 \ln C + a_2 \ln H + a_3 \ln age + a_4 \ln exper + a_5 \ln school$
Note: *t*-statistics are reported in parentheses.
[a]Significantly different from zero at 0.01 level.

The results of the estimation indicate that individual productivity is positively related to available energy and experience, and negatively related to age and the level of household responsibilities. Schooling is not a significant factor in determining productivity. This result is consistent with other studies that have shown that schooling is not a significant factor in determining wage or income within an occupational group.

## V. DEMAND EQUATIONS

We now estimate the following demand equations in reduced form:

$$L = g_1(q, r, s, V, \mathbf{I})$$
$$K = g_2(q, r, s, V, \mathbf{I})$$
$$H = g_3(q, r, s, V, \mathbf{I})$$

[3]Alternative specifications of the production function which included higher order values of age, experience and schooling were tested. The higher order terms were not significant.

The term $L$ represents total leisure time and is equal to 16 hours plus time spent on break. $K$ is the total number of calories consumed per work day by the individual. The value of $H$ ranges from one to five and represents the level of household responsibilities. The scalars $q$ and $r$ represent the piece rate per unit of output and the dollar cost per calorie for the diet chosen by the worker, respectively. The term s is defined as

$$s = -qF_2(C, H, \mathbf{I})$$

and represents the implicit marginal cost of expending energy level $H$ off the job when the market production function is $F$. $V$ is nonlabour income, and $\mathbf{I}$ is a vector of personal characteristics.

The piece rate $q$ varied among the three operations of hand tailor, presser and pattern cutter. The dollar cost per calorie $r$ is calculated as the total household food bill per week divided by the total weekly caloric requirements of the household. The value of $s$ is calculated using the piece-rate $q$ and the production function $F$ which was established in Section IV. Although the variables $L$, $K$ and $H$ appear in the specification of $F$, no stochastic problems arise in estimating the demand equations since the production function is purely technological and not a function of individual choice.

The individual characteristics include sex, age, marital status, number and age of children, hours of sleep and basal metabolic rate.

All estimation was performed by ordinary least squares. The following equations were estimated after omitting variables of low significance with the results presented in Tables 3, 4 and 5.

$$L = a_0 + a_1 q + a_2 r + a_3 s + a_4 V + a_5\, jobd + a_6\, kid + a_7\, age$$
$$K = b_0 + b_1 q + b_2 r + b_3 s + b_4 V + b_5\, sexd + b_6\, jobd + b_7\, sleep + b_8\, BMR$$
$$H = c_0 + c_1 q + c_2 r + c_3 s + c_4 V + c_5\, sexd + c_6\, mard + c_7\, teen + c_8\, kid + c_9\, baby$$

where

*jobd* = 1 if hand tailor
*sexd* = 1 if male
*mard* = 1 if married
*teen* = number of children aged 13–18
*kid* = number of children aged 6–12
*baby* = number of children under 6 years old
*sleep* = number of hours of sleep per night
*BMR* = basal metabolic rate
*age* = age in years

The estimation results of the leisure demand equation indicate that an increase in the piece rate reduces leisure time. Since leisure time is defined as sixteen hours plus time spent on break (all workers were required to spend eight hours at the work site), this indicates that the supply of labour time is positively related to the piece rate. Higher cost per calorie decreases labour time supplied. This is caused by the reduction in the quantity of calories demanded at a higher cost per calorie (see Table 4), leading to an increase in leisure time which is less energy demanding

Table 3. *Regression coefficients for variables in leisure demand equation*

| Variable | Coefficient equation 1 | Coefficient equation 2 |
|---|---|---|
| *q* | −0.292[a] | −0.256[a] |
| | (4.07) | (3.66) |
| *r* | 49.77 | |
| | (1.15) | |
| *s* | 0.0213 | |
| | (1.60) | |
| *V* | 0.000003 | 0.0000024 |
| | (0.68) | (0.64) |
| *jobd* | −0.787[a] | −0.794[a] |
| | (5.09) | (5.27) |
| *kid* | 0.149[a] | 0.142[a] |
| | (2.95) | (2.92) |
| *age* | −0.0056[a] | −0.0049[b] |
| | (2.22) | |
| Average *L* | 16.42 | 16.42 |
| Constant | 18.83 | 18.79 |
| $R^2$ | 0.31 | 0.29 |
| Number of observations | 135 | |

Estimated equations:

(1) $L = a_0 + a_1 q + a_2 r + a_3 s + a_4 V + a_5 jobd + a_6 kid + a_7 age$

(2) $L = d_0 + d_1 q + d_2 V + d_3 jobd + d_4 kid + d_5 age$

Note: *t*-statistics are reported in parentheses.
[a]Significantly different from zero at 0.05 level.
[b]Significantly different from zero at 0.10 level.

Table 4. *Regression coefficients for variables in calorie demand equation*

| Variable | Coefficient |
|---|---|
| *q* | 181.8 |
| | (1.58) |
| *r* | −106488.0[b] |
| | (1.64) |
| *s* | 29.0 |
| | (1.03) |
| *V* | 0.0028 |
| | (0.46) |
| *sexd* | 696.4[a] |
| | (3.18) |
| *jobd* | 550.8[a] |
| | (2.03) |
| *sleep* | −53.4 |
| | (1.44) |
| *BMR* | −0.12 |
| | (0.31) |
| Average *K* | 1751.5 |
| Constant | 504.7 |
| $R^2$ | 0.38 |
| Number of observations | 135 |

Estimated equation:

$$K = b_0 + b_1 q + b_2 r + b_3 s + b_4 V + b_5 sexd + b_6 jobd + b_7 sleep + b_8 BMR$$

Note: *t*-statistics are reported in parentheses.
[a]Significantly different from zero at 0.05 level.
[b]Significantly different from zero at 0.10 level.

Table 5. *Regression coefficients for variables in household responsibilities equation*

| Variable | Coefficient |
|---|---|
| *q* | 0.330[a] |
| | (4.33) |
| *r* | −194.9[a] |
| | (2.39) |
| *s* | −0.304[a] |
| | (8.1) |
| *V* | 0.00001 |
| | (1.35) |
| *sexd* | −1.628[a] |
| | (7.42) |
| *mard* | 0.429[a] |
| | (2.92) |
| *teen* | 0.161 |
| | (1.90) |
| *kid* | 0.179[a] |
| | (1.97) |
| *baby* | 0.216[a] |
| | (1.97) |
| Average *H* | 2.50 |
| Constant | 2.177 |
| $R^2$ | 0.86 |
| Number of observations | 135 |

Estimated equation:

$$H = c_0 + c_1 q + c_2 r + c_3 s + c_4 V + c_5\, sexd + c_6\, mard + c_7\, teen + c_8\, kid + c_9\, baby$$

Note: *t*-statistics are reported in parentheses.
[a]Significantly different from zero at 0.05 level.

than labour time. Leisure time is positively related to the implicit marginal cost of off-the-job energy expenditure, indicating that a greater cost of energy expenditure off the job leads to a greater fatigue effect, thus requiring greater leisure time. Leisure time is also positively related to other nonlabour income. The results involving the cost per calorie, the implicit marginal cost of off-the-job energy expenditure, and other nonlabour income are not, however, significant at the 0.10 level.

Since hand tailoring is performed sitting while pressing and cutting are performed standing, we would expect that hand tailors require less break time than do workers performing tasks that require standing for long periods. We find that on average, hand tailoring reduces leisure time by 47.2 minutes per day relative to pressers or cutters.

Additional children aged 6–12 increase leisure time by 8.9 minutes per day. Regressions performed including children aged 13–18 and under 6 years old indicated these variables were not significant. This result may be caused by the need of greater parental attention to gradeschool age children, such as parent–teacher conferences, which does not extend to teenagers and is not relevant to preschoolers.

An additional ten years of age reduces leisure time by 3.4 minutes per day. This may indicate that older workers need to spend more time on the job to be as productive as they had been when they were younger.

In order to compare these results to more traditional labour supply estimations, an additional leisure demand equation was estimated omitting the cost per calorie and the implicit marginal cost of off-the-job energy expenditure. The results of this estimation are presented in Table 3A. On the basis of an $F$-test, the hypothesis of equality of the two leisure demand equations can be rejected. When $r$ and $s$ are included in the leisure demand equation, an increase in the piece rate $q$ of one dollar reduces leisure time by 17.52 minutes per day. When $r$ and $s$ are omitted, the results of the estimation indicate that an increase in $q$ of one dollar reduces leisure time by 15.36 minutes per day, or by 11% less than when $r$ and $s$ are included in the estimation. This is caused by ignoring the cost of energy expenditure in terms of the cost per calorie and the energy cost of off-the-job household responsibilities. The greater these costs, the greater the leisure time required which is less energy-demanding than is labour time.

It is interesting to compare the wage elasticities of labour time determined in this study to those found in other studies. The elasticities found in this study are 0.24 and 0.22 for the two labour supply equations. The elasticities determined by Finegan (1962), Rosen (1969), and Winston (1966) all fall within the range $-0.07$ to $-0.35$. It should be noted that these elasticities are derived from studies in which the work week was the time period used and not the work day which has been used in this study. Thus, in interpreting their results it is not clear if the work week reflects individual preferences or employer preferences. The situation studied here allowed almost complete freedom of the worker in choosing the quantity of labour time to supply. Contrary to the results mentioned, we find that the supply of labour time is positively related to the wage rate.

The estimation results of the calorie demand equation indicate that the piece rate is positively related to calorie demand. Thus, a higher piece rate induces an increase in the total demand for energy which may be used for both on and of the job energy expenditure. As expected, an increase in the cost per calorie reduces the quantity of calories demanded. An increase in the implicit marginal cost of off-the-job energy expenditure increases the quantity of calories demanded, indicating that greater energy expenditure off the job requires greater total energy available to the body. However, this result is not significant at the 0.10 level. The dummy variables associated with sex = male and job = hand tailor are positively to related calorie demand. Other nonlabour income hours of sleep, and BMR are not significantly related to calorie demand.

The estimation results of the household responsibilities equation indicate that greater implicit marginal cost of energy expenditure off the job reduces household responsibilities. The cost per calorie is negatively related to household responsibilities, indicating that a higher cost of energy reduces the quantity of energy provided to perform household activities. The piece rate is positively related to household responsibilities, suggesting that workers who are efficient on the job are also efficient in performing household activities. Other nonlabour income is positively related to household responsibilities, which indicates specialization in higher market or nonmarket activities within the household. The traditional observation that women have more home responsibilities than do men is confirmed by this study. This is also true for married workers. Increases in the number of children of any age also increase household responsibilities.

An interesting body of work that is related to this study concerns the allocation of time within the household. Formulated by Becker (1965) this theory emphasizes that goods and services alone do not yield utility, but require an input of the consumer's time. Based on this theory is the work of Gronau (1977) which formalizes the trichotomy of work in the market, work at home and leisure. Gronau's model yields implications regarding changes in time spent at work in the market, work at home, and leisure, as a result of changes in wage rates, nonlabour income, children, schooling and marital status. This model differs from the model developed in this study in that the measure of work at home used by Gronau refers to time spent on these activities rather than the energy intensity of these activities. However, both studies find that an increase in the market wage rate reduces work at home, and that an increase in nonwage income does not affect the work at home of an employed person.

## VII. CONCLUSION

The purpose of this study was to examine the effect of the supply of effort on the effective supply of labour. A model was developed in which the worker maximizes utility, subject to a budget constraint which depends on the effort exerted by the worker on the job, by choosing quantities of goods, leisure time, calories and household responsibilities. In order to estimate the demand equations, the particular specification of the technological production function was established, and the demand equations for leisure, calories and household responsibilities were estimated.

The results of the estimation of the production function indicate that the quantity of available energy and years of worker experience are positively related to output, that greater household responsibilities and age are negatively related to output and that schooling is not a significant factor in determining output.

The wage elasticity of labour time derived in this study is 0.24. This is based on labour supply per day as the measure of labour time. Other studies which have used labour supply per week as the measure of labour time have found negative elasticities or elasticities not significantly different from zero. Workers in this study were free to supply any quantity of labour time per day, so the elasticity derived here is extremely sensitive to worker preferences.

Other factors positively related to leisure time are the cost per calorie, the implicit marginal cost of off-the-job energy expenditure, the operations which are performed standing rather than sitting and the number of children aged 6–12. Aging is negatively related to leisure time indicating that older workers may need to spend more time on the job to compensate for a reduction in the intensity of effort.

The quantity of calories demanded is positively related to the piece rate and the implicit marginal cost of off-the-job energy expenditure, and negatively related to the cost per calorie. The level of household responsibilities is negatively related to the implicit marginal cost of off-the-job energy expenditure and the cost per calorie, and positively related to the piece rate, being a woman rather than a man and the number of children of any age.

One implication of this study is that an increase in available energy will increase worker productivity. This relationship between diet and productivity has been observed under semiexperimental conditions in Germany during World War II (Leibenstein, 1957). As the war progressed and the caloric value of the food rations decreased, the daily output of coal per miner declined. The same relationship between declining caloric value of rations and declining output was observed in the German steelworks. A group of coal miners and a group of workers engaged in building railway tracks were given increased rations to see if this could improve the low production. It was found that output did increase as food rations increased.

The relationship between diet and productivity was examined theoretically by Leibenstein (1957), who concluded that a labour deficit at low wages may be caused by inadequate nutrition. This is because workers with inadequate diets are physically incapable of supplying more effort on the job. The efficiency-wage hypothesis says that the amount of work a labourer can be expected to perform depends on his energy level, his health and his vitality. These in turn are expected to depend on his consumption level. This model was made more rigorous by Stiglitz (1976) who solves for the wage which minimized cost per efficiency unit, where efficiency is determined by consumption. Bliss and Stern (1978) examined the issues of workers' preferences between work and consumption. They felt that utility will initially increase and then decrease with consumption. This is because they feel that a little extra work together with a little extra consumption is preferred to total idleness, but that at extreme levels of work, some relaxation together with some reduction in consumption would be welcomed.

It is interesting to note that although the recommended dietary allowances (RDA) for the reference man and women are set at 2700 and 2000 calories per day, respectively, the average caloric consumption per work day found in this study was 1751.5 calories per work day. Caloric intake well below the RDA was also found in the Health and Nutrition Examination Survey. While workers were not underweight, many reported a dietary pattern of undereating during the work week and overeating on weekends. The result of this dietary pattern is to maintain a stable weight for the individual while providing insufficient energy during the week and excess energy on weekends. A policy response to this situation was explored in an experiment performed by Haggard and Greenberg (1935). A group of workers sewing canvas tops of tennis shoes was divided into a control group and an experimental group. The members of the experimental group were provided with a glass of milk and a piece of angel food cake midmorning and midafternoon. It was found that the average output of the experimental group exceeded that of the control group during the periods of the between-meal feedings. This suggests that there may be some optimal subsidy at which firms would profit from making low-cost food available to their workers.

## APPENDIX

*Comparative statics of the model of Section II.*

Solving for the terms of the matrix $A^{-1}$ yields the following:

$$a_{11} = \frac{\partial X/\partial p + X\partial X/\partial V}{\lambda}$$

$$a_{12} = \frac{\partial X/\partial q + (24 - L)F_1(\partial X/\partial r - K\partial X/\partial V) - \partial X/\partial(qF_2) + (24 - L)F\partial X/\partial V}{\lambda F}$$

$$a_{13} = \frac{\partial \mathbf{X}/\partial r - K\partial \mathbf{X}/\partial V}{\lambda}$$

$$a_{14} = \frac{-\partial \mathbf{X}/\partial(qF_2)}{\lambda(24-L)}$$

$$a_{15} = \partial \mathbf{X}/\partial V$$

$$a_{21} = \frac{\partial L/\partial \mathbf{p} + \mathbf{X}\partial L/\partial V}{\lambda}$$

$$a_{22} = \frac{\partial L/\partial q + (24-L)(\partial L/\partial r + K\partial L/\partial V) - F_2\partial L/\partial(qF_2) + (24-L)F\partial L/\partial V}{\lambda F}$$

$$a_{23} = \frac{\partial L/\partial r + K\partial L/\partial V}{\lambda}$$

$$a_{24} = -\frac{\partial L/\partial(qF_2)}{\lambda(24-L)}$$

$$a_{25} = \partial L/\partial V$$

$$a_{31} = \frac{\partial K/\partial \mathbf{p} + \mathbf{X}\partial K/\partial V}{\lambda}$$

$$a_{32} = \frac{\partial K/\partial q + (24-L)F_1(\partial K/\partial r + K\partial K/\partial V) - F_2\partial K/\partial(qF_2) + (24-L)F\partial \dot{K}/\partial V}{\lambda F}$$

$$a_{33} = \frac{\partial K/\partial r + K\partial K/\partial V}{\lambda}$$

$$a_{34} = -\frac{\partial K/\partial(qF_2)}{\lambda(24-L)}$$

$$a_{35} = \partial K/\partial V$$

$$a_{41} = \frac{\partial H/\partial \mathbf{p} + \mathbf{X}\partial H/\partial V}{\lambda}$$

$$a_{42} = \frac{\partial H/\partial q + (24-L)F_1(\partial H/\partial r + K\partial H/\partial V) - F_2\partial H/\partial(qF_2) + (24-L)F\partial H/\partial V}{\lambda F}$$

$$a_{43} = \frac{\partial H/\partial r + K\partial H/\partial V}{\lambda}$$

$$a_{44} = -\frac{\partial H/\partial(qF_2)}{\lambda(24-L)}$$

$$a_{45} = \partial H/\partial V$$

Using the negative semidefinite properties of $A^{-1}$, we can derive the following implications:

$$a_{11} \leqslant 0 \quad (1)$$

$$a_{33} \leqslant 0 \quad (2)$$

$$a_{13} = a_{31} \quad (3)$$

$$a_{11}a_{33} - a_{13}^2 \geqslant 0 \quad (4)$$

$$a_{22} \leqslant 0 \quad (5)$$

$$a_{44} \leqslant 0 \quad (6)$$

$$a_{12} = a_{21} \quad (7)$$

$$a_{14} = a_{41} \quad (8)$$

$$a_{23} = a_{32} \quad (9)$$

$$a_{24} = a_{42} \quad (10)$$

$$a_{34} = a_{43} \quad (11)$$

$$a_{11}a_{22} - a_{12}^2 \geqslant 0 \quad (12)$$

$$a_{22}a_{33} - a_{23}^2 \geqslant 0 \quad (13)$$

$$a_{33}a_{44} - a_{34}^2 \geqslant 0 \quad (14)$$

$$a_{11}a_{44} - a_{14}^2 \geqslant 0 \quad (15)$$

$$a_{22}a_{44} - a_{24}^2 \geqslant 0 \quad (16)$$

$$a_{11}a_{22}a_{33} + 2a_{12}a_{13}a_{23} - a_{22}a_{13}^2 - a_{11}a_{23}^2 - a_{12}^2a_{33} \leqslant 0 \quad (17)$$

$$a_{22}a_{33}a_{44} + 2a_{23}a_{34}a_{24} - a_{33}a_{24}^2 - a_{22}a_{34}^2 - a_{44}a_{23}^2 \leqslant 0 \quad (18)$$

$$a_{11}a_{33}a_{44} + 2a_{13}a_{34}a_{14} - a_{14}^2a_{33} - a_{11}a_{34}^2 - a_{13}^2a_{44} \leqslant 0 \quad (19)$$

$$a_{11}a_{22}a_{44} + 2a_{12}a_{24}a_{14} - a_{22}a_{24} - a_{11}a_{24}^2 - a_{44}a_{12}^2 \leqslant 0 \quad (20)$$

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