\[ x_0 = (0.44 - 0.29 1.84 3.56 5.41 3.73) \]
\[ w_0 = (1, 4, 0, 2, 3, 7, 9) \]

Now we consider the input-output projections with households included in the processing sector. Given a hypothetical demand vector

\[ f_0 = (11, 14, 0, 2, 7, 9) \]

\[ k = 1 \cdot (1 - b + c) \]

\[ \lambda = 1 - (a + b \cdot c - (1 - b) \cdot k) \]

\[ \delta = b \cdot h \cdot k + \Delta \lambda + k \cdot h \cdot c \cdot k = b \cdot h \cdot c \cdot k \]

\[ \lambda = 1 - (a + b \cdot c - (1 - b) \cdot k) \]

\[ \phi = b \cdot h \cdot c \cdot k \]

\[ x_0^* = [c^{-1} \cdot f_0 + (1.0 \cdot k \cdot g^0)] = (89.90, 81.05, 51.86, 56.99, 63.93, 68.79) \]

\[ \phi = b \cdot h \cdot c \cdot k \cdot f_0 + f_0 = 40.95 \]

\[ x_1^* = [f_0 + (1.0 \cdot k \cdot g^0)] = (20.07, 15.89, 7.40, 13.22, 20.46, 18.41) \]

\[ x_2^* = (1.0 \cdot g^0) = 107.00 \]

\[ x_3 = (1.0 \cdot g) = 80.02 \]

\[ e_5 = (1.0 \cdot h \cdot f_0^* + h \cdot c \cdot k + f_0 + (1.0 \cdot g) \cdot g^0 = 27.49 \]

Note that the sum of static output projections and errors may not add up exactly to the true values due to the rounding error. Also the household input coefficients and sectoral consumption coefficients are quite larger than would ordinarily be the case in a model based on actual data. This fact may account for the relatively large errors in the closed model.

References


York, Oxford University Press, 1953.


1969.

In calculating the benefits associated with the introduction of a transport project it is usually assumed that the average cost of producing transportable commodities is constant. Thus, if a road is to be constructed between two production centers, the benefits associated with such a project are simply estimated as the direct resource savings that result from shipping presently traded goods at the lower transport price. If the production functions of the competing centers are generalized to allow for the existence of comparative advantages and economies of scale, however, this calculation underestimates the true social savings of the project.

The purpose of this paper is to determine under what conditions this underestimation is sufficiently large that it would seriously undermine the validity of traditional calculations.

A similar exercise was recently performed by Mohring and Williamson [6]. In their model, however, the market structure is assumed to be completely monopolistic: a single firm exists in the relevant market space and each of its plants enjoys unlimited production scale economies. “Government regulations” are assumed to exist that require the firms to charge the same price to all consumers, and, more importantly, the number and location of the firm’s plants are unconstrained control variables. It is also assumed that the population density is uniform over space, and that there are no cost advantages to building plants in any particular locations.

*Federal Trade Commission; however, any views expressed here are not necessarily shared by the FTC.

*For example, see [1], [2], [3], [6].

Under these conditions, Mohring and Williamson ask how the firm will change its plant locations and sizes when transport costs fall by twenty-five percent. The scale benefits, that is, the increase in producer surplus, generated by the existence of fewer but larger plants are then compared to the direct benefits of the reduction in transport costs.

By contrast, the model employed in this paper assumes complete competition, and fixed firm locations. In this regard, it is initially assumed that plant locations are determined by the location of natural resources that are expensive to ship. But, later, when the model is generalized to allow for urban centers, firms may be assumed to locate in urban areas owing to any number of other cost advantages: perhaps, for example, there are cost savings from locating close to suppliers or large labor pools. In any event, in our model, a single number of competing firms are located at points l and 2. Each firm is characterized by a U-shaped cost curve but each group of firms is subject to external technological economies of scale. When transport costs fall in our model, the market share of the more efficient group of producers increases; owing to external economies of scale, a net scale benefit occurs. Since factor prices are taken as given, and since the transport industry is assumed to be competitive, consumers gain all of the benefits from the reduction in transport costs.

As it turns out, the assumptions of a monopolistic or competitive model do not affect the main results of the analysis; either assumption
TRANSPORT BENEFITS AND ECONOMIES OF SCALE

The road is used only for the transportation of a single commodity (its quantities denoted by \( Q_0 \)).

The long run supply conditions (net of transport costs) for each production center are shown to be \( KK' \) for the group of firms located at 1 and \( HH' \) for the group located at 2. The negative slope of these schedules reflects the existence of technological economies of scale which, we suppose, are internal to each group of firms, but external to each firm; hence, the competitive nature of the market is preserved.

Moreover, economic rents to factors of production are precluded so that social welfare is

3 But these assumptions and others will be subsequently relaxed.

4 For example, in the industry under analysis, if a new firm enters the market and supplies an identical commodity, then the price will fall, and the output of the existing firms will increase.

5 The relationship between the number of firms and the output of each firm is given by the inverse of the supply function for each firm.

6 The relationship between the price of a commodity and the cost of producing it is given by the inverse of the supply function for each firm.
duction in transport costs, and these net gains can be usefully separated into several components. First, at the new level of transport cost, fewer resources are devoted to the transportation of the commodity to the same destination as previously existed and this direct gain is measured by area KQFQ in the figure. Second, as group 1 producers expand their output to Q1, the c.i.e. price of their output falls from Q0 to Q4 owing to economies of scale, and thereby a scale gain equal to area ABCD is conferred to consumers previously served by 1. Note, however, that this beneficial scale effect is partially offset by a corresponding loss (measured by area EFGQ) resulting from the contraction of the competing center's output to Q2 units. Prior to the restructuring, a similar loss also accrued to the consumers who reside between d1 and d2. In the original equilibrium this gain to the marginal consumer at df of transporting the commodity from 1 was offset by the competing producers was C' while the additional transport cost which exactly offset this gain was (C'-N). Under the new transport schedule, however, the benefits of C' exceed the costs (CP'-PQ) by the distance PQ. Each succeeding consumer between d1 and d2 experiences a similar, but decreasing, net gain from transporting the commodity further from region 1 until at d1, the marginal consumer is again indifferent. The net gain is an integration term which includes both direct transport savings as well as scale effects and is measured by area MPQ. Of course, since each marginal consumer at C1 makes its decision to substitute toward I according to the cost schedule at some particular point d1 between df and d2, a consumer surplus would be subsequently realized as the relative cost of center I's output continued to fall as its market expanded past the point d1. This additional scale gain is measured by the triangle C'D'.

Measurement of the Scale Adjustment

It is easy to measure the relative importance of the scale effect if the interaction term (area MPQ in the figure) is ignored. In particular, it is straightforward to derive the direct resource savings D associated with the transport project (area KPDQ) as

\[ D = \frac{2\beta r_2^2}{4} \left( \frac{Q_1 + r_2}{b + r_1} \right)^2 > 0. \tag{4} \]

Furthermore, if we deliberately overstate the scale effect by an area equal to C'D', thereby introducing an upward bias into the calculation, the scale gain S (that is, area |ABCD - EFGQ| + C'D') may be measured by

\[ S = \frac{-\beta r_2^2}{4} \left( \frac{Q_1 + r_2}{b + r_1} \right)^2 > 0 \text{ if } b > 0, \tag{5} \]

where \( r_1/r_2 \), (c) is the new transport rate relative to the old. Therefore, the scale gain relative to the direct gain can be expressed according to the ratio

\[ \frac{S}{D} = \frac{-\beta r_2^2}{4} \left( \frac{Q_1 + r_2}{b + r_1} \right)^2 \frac{1}{\left( \frac{Q_1 + r_2}{b + r_1} \right)^2} > 0 \text{ if } b > 0, \tag{6} \]

where it is seen that the scale adjustment in this model is relatively more important, (a) the more acute economics of scale in production, (b) the larger the comparative advantage held by one production center (in this case I), and (c) the more dramatic the reduction in transport cost.

\[ \frac{\Delta(SD)}{\Delta b} > 0, \quad \frac{\Delta(SD)}{\Delta r_1} > 0, \quad \frac{\Delta(SD)}{\Delta r_2} < 0. \tag{6a} \]

Equation (6) was solved for the following parameter values. The c.i.e. price at center I for the first increment of production (the vehicle distance 8K in figure 1), say C1, was arbitrarily chosen to equal 5. The average cost schedule was then restricted to remain positive over the range of output Q2'. Choosing Q2' equal to 100 units, this restricted the slope of the supply schedule to \( a = -0.2b^2c_1^2Q^2 = 0.5 \). Additionally, to restrict the model within the boundaries of available empirical estimates, the elasticity of supply in our model was restricted to be generally more positive than \(-5\) [4], [5], [10]. The elasticity of production for the industry as a whole is denoted by \( e \) and was calculated at the weighted average of the elasticity calculated at each center's point of original equilibrium; choices of \( b \) equal to -0.01 and -0.02 generated values of \( e \) in the vicinity of -1.0 and -5.0, respectively. Additionally, the note that the c.i.e. price at the first increment of output at center I, say C10, is 5.0. Values of \( b \) were chosen to be 5.1 and 2.5. Expressed as a percentage of C10, the comparative advantage parameter is depicted in \( \rho_2 \); thus, center I's average cost was assumed to be \( 0.91, 1.07 \) and 333 percent lower than center II's average cost at the first incremental unit of output at center II.

The percentage reduction in transport costs--(\( r_1 - r_2 \)Q0) was alternatively chosen to equal \(-10, -20, -40 \) and -50. The level of the initial transport rate was chosen to be high enough to satisfy the non-specialization condition given by (1). Given values of \( b \) that range as high as 2.5 and values of \( r_0 \) that range as high as 0.3, this condition (\( r_0 > \sqrt{SD} / b \)) required a value of \( r_0 \) that exceeded 0.55; an initial value of \( r_0 \) was chosen to equal 10. Note that even though an initial transport rate is chosen to satisfy (1), this condition is not necessarily satisfied at some levels of the new transport rate \( r_1 \); that is, under some conditions, a reduction in the transport rate from \( r_0 \) to \( r_1 \) will lead to the complete elimination of one center of production. Also note that the choice of the initial level of the transport rate helps to determine the relative importance of transport costs in the final price; this transportation share, denoted by \( h_2 \), is calculated for the average consumer served by either group of firms.

The calculations are presented in table 1. The choices of the slope coefficients--\( b = -0.01, -0.03 \)--imply a range of supply elasticities within the range of -10 to -5.14. Additionally, the parameters chosen generate a set of delivery charges that account for approximately 37% to 533 percent of delivered price. Finally, the market share of production center I in original equilibrium, denoted by \( a_i \), rises with the level of center I's comparative advantage and with the level of economies of scale, its range varies from 0.28 to 0.67. In general, the change in the market share of center I from the old to the new equilibrium (\( a_i - a_{i0} \)) is higher, the higher the absolute level of its comparative cost advantage; in addition, it is also higher, the larger the reduction in transport cost. In fact, in one instance, when the percentage transport cost reduction was -50, center I assumed a market share of unity when the supply elasticity was -314. In this case, condition (1) is violated for the transport rate \( r_1 \); therefore...
the scale to direct gain was not calculated according to (6). Instead, the areas comparable to $ABCD + CDF$ were calculated directly and compared to the direct transport savings.

For all entries characterized by relatively "small" economies to scale, that is, those corresponding to an elasticity of supply equal to $-1.07$ or $-1.11$, the scale to direct gain was less than nine percent, regardless of either the level of comparative advantage or the magnitude of the reduction in transport costs. In fact, in ten out of twelve of these cases the scale-to-direct ratio was less than three percent. When scale economies were relatively high, that is, when $e$ was in the range $-4.11$ to $-5.14$, the scale-to-direct gain was substantially greater than ten percent when the percentage reduction in transport cost was $-50$ or when the level of center $i$’s comparative advantage reached fifty percent in terms of its own price, $Q_i$. When the transport cost reduction was (absolutely) $40$ or less, however, and when the level of comparative advantage did not exceed $16.7$ in terms of $Q$, the scale-to-direct gain fell below ten percent.

The results are also affected, however, by the choice of the level of the initial transport rate $r_0$. Given the choice $r_0 = 1$, the share of transport costs in price in table 1 varies only with the level of economies of scale: the more acute the economies of scale, the lower is the f.o.b. price relative to the average delivered price. But as long as the initial transport rate is chosen to satisfy the condition in (1), the level of $\lambda$ can be independently affected by the choice of $r_0$. The lower the choice of $r_0$, subject to (1), the less important are transport costs in final price; hence, a percentage reduction in $r_0$ will lead to a lower dollar direct transport gain compared to the scale gain.

For example, when $r_0$ is set equal to $0.67$ (which satisfies (1) for all observations), the value of $\lambda$ falls by approximately ten percentage points for the same observations considered above; these calculations are shown in the second part of table 1. The scale-to-direct gain ratio increases considerably, as shown. The ratio remains below ten percent in the cases in which the elasticity of supply is equal to or more positive than $-1.11$ and when the absolute percentage cost reduction is $20$ or less. But, in other cases, the scale gain becomes very important, even exceeding the direct savings from the transport improvement in some circumstances. These illustrations suggest that the benefits of a transport project may be seriously underestimated under certain realistic conditions. In this regard, it is worth noting that the transport share terms are not comparable to empirical observations because we have thus far ignored the possibility of the existence of urban populations at centers $I$ and $II$. In other words, if intraurban transport costs were negligible, and if 200 units of the commodity were consumed by urban consumers at the points of production, the values of $\lambda$ in table 1 would be reduced by two-thirds.

In general, then, it would appear that within the range of values considered here, the importance of the scale effect in the usual estimate of transport benefits would depend critically on the level of scale economies, the degree of comparative advantage between centers of production, the level of transport costs, and the percentage change in transport cost induced by a transport project. The model does imply, however, that the scale effect might reasonably be ignored when the elasticity of supply is not significantly more negative than $-10$, and the absolute cost reduction is not more than $20$. Outside these bounds, however, the model suggests that the traditional calculation of transport benefits may seriously underestimate the true benefits of a project. In this regard, our model yields different policy implications than those of Mohring and Williamson. Using an elasticity and a slight average cost in the range $-0.5$, Mohring and Williamson [8] found that a twenty-five percent reduction in transport cost in their model would lead to scale-to-direct ratio that was uniformly less than fifteen percent. They concluded that, as a practical matter, scale effects from reductions in transport costs could be ignored in transport benefit calculations. But our results suggest that this inference may be specific to their model, and to their consideration of a moderate transport cost reduction. Our model suggests that scale effects could easily account for twenty to fifty percent of the total benefits of a transport project. Moreover, it will become apparent, as we generalize the model, that the importance of the scale effect could become even greater under some conditions. But the general irrelevance of the scale effects when scale economies remain small, particularly when transport cost reductions are small, will remain intact.

**Generalizations**

**Internal Markets**

Let us first generalize the model to allow for "internal" markets at the points of production $I$ and $II$. In particular, assume that consumers at either center of production exhibit vertical demand curves over the relevant range of prices, and also assume that the consumers at center $I$ purchase $Q_I$ units of the commodity per period. The total output of firms at $I$ and $II$ is now $Q = Q_I + Q_II$, $f = I, II$, where $Q_I$ is output pro-

### TABLE 1

<table>
<thead>
<tr>
<th>Comparative Advantage</th>
<th>Economic</th>
<th>Market</th>
<th>Transport</th>
<th>Share</th>
<th>Share</th>
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<th>-20</th>
<th>-40</th>
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<td>$e_2$</td>
<td>$e_3$</td>
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<td>$Q_3$</td>
<td>$Q_4$</td>
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<td>0.009</td>
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<td>-0.011</td>
<td>0.55</td>
<td>0.002</td>
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<td>0.583</td>
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<td>0.31</td>
<td>0.009</td>
<td>-42.5</td>
<td>0.001</td>
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<td>6. 2.533</td>
<td>-1.11</td>
<td>0.69</td>
<td>0.42</td>
<td>0.020</td>
<td>-67.9</td>
<td>0.023</td>
<td>0.750</td>
<td>0.016</td>
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<td>0.750</td>
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<td>0.750</td>
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</tbody>
</table>

The calculations in this table were made assuming $r_0 = 1.0$. The non-specialization condition was not satisfied at $r_1$, hence the calculation was not made according to (6).
The implications of this adjustment are two-fold. First, since output is produced in either center according to increasing returns to scale, a higher level of consumption in one center gives firms in that market a comparative advantage in cost at the point of production. Therefore, the difference in average cost between centers I and II prior to any export activity is now comprised of two parts: (a) a technical cost advantage (due to different factor costs or technology, etc.), and (b) a scale advantage (due to differential levels of home consumption). In other words, the parameter $b$ in (2) is now written as

$$b = A + b_1 (Q_1 - Q_2) + b_2 > 0$$  (9)

where $A > 0$ denotes the technical advantage (or disadvantage) of I over II, and $b_1 (Q_1 - Q_2)$ denotes the corresponding scale advantage (or disadvantage). Note that $b$ may be positive even if $A$ is negative as long as the level of consumption at I is sufficiently large compared to II and vice versa.

Second, the scale effect is no longer solely evaluated in terms of its effect on the external market. Instead, the effects of lower and higher production prices on the internal markets must now be considered. In other words, in terms of figure I, the beneficial redistribution in production price from 0.8 to 0.4 now confers a benefit to consumers of the output $Q_1$ in the home market at I while the increase in price from 0.8 to 0.6 now adversely affects consumers in the home market at II. If the transport project does not affect internal consumers directly, then the direct savings of the transport project calculated above in (4) will not be affected by this modification.

The scale effect, however, is now calculated as $S$, and its relation to $S$ can be increased in $3^{11}$.

$3^{11}$That is, if $Q_2/(Q_1)$ is the output produced and consumed at the point of production (III), then the scale effect calculated in (4) would read

$$S = \frac{1}{b} \left( A \left( b + r_1 \right) + r_1 \right) > 1$$ if $A < b > 0$. (10)

where $b$ is assumed to exceed zero (that is, region I still holds the net cost advantage). Note that the ratio equals unity if $A = b$ (that is, if internal consumption is identical at either point of production, that is, $Q_1 = Q_2$, but equals $r_1/b$ ($> 1$ by (10)) if there is no technical advantage from production at either I or II (that is, if $A = 0$). In general, the scale adjustment calculated in (10) will underestimate the true scale effect as long as $A < b > 0$.

To evaluate the impact of internal markets on our earlier conclusions, we calculated $S^*$ for selected values of $b$ and $b$. In particular, $b$ was set equal to unity ($Q_1 = Q_2 = 67$) and $b_1 = 0.50$ or $0.75$, or $0.50$ or $0.75$, or $0.50$ or $0.75$. Moreover, the calculations were made for absolute transport rate reductions equal to 0.2 and $A$ (where $r_1 = 0.2$). It was initially assumed that the internal market at center II was twenty-five percent and fifty percent larger than center I. The calculation was also made assuming that $Q_1 = 200$, $Q_2 = 0$.

The adjustment factor $S^*$ is considerable in most cases; ranging from 1.60 to 5.67. Using this ratio, the scale-to-direct gain was recalculated as $S^*/S$ and compared to its original value, $S^*$. In general, the calculations were made for cases in which $S^*$ was relatively small; in ten of twelve cases the ratio was less than one percent. For these cases the urban population adjustment, while large, does not affect the main policy conclusions made above.

On the other hand, while not shown in the table, it is clear that the existence of urban population could substantially increase the importance of the scale effect in cases in which the value of $S^*$ was already, say, above twenty percent. Thus, the existence of urban population tends to strengthen the suspicion that scale economies could be important in transport benefit calculations but it does not generally alter the notion that the adjustment is unimportant when scale economies are small.

Partial Project

Finally, suppose that the transport project does not completely connect centers I and II, but that rather it starts at one center but that, at some point prior to reaching the other center, it changes direction toward unrelated markets. Then, the scale effect calculation must be taken in evaluating the importance of the scale effect relative to the direct effect of the project. To illustrate, consider figure I once again, and suppose that a railroad was constructed from center I to a point $Q_1$ units of distance away (then either stopped or turned in a different direction to unrelated markets). In this case, the direct transport savings is measured by $KIN$ but, since pattern of trade between I and II is not affected by the project, no scale gain is generated.

Alternatively, if the project only includes a road or railroad through the points $d_2$, then the implications for the scale-co-direct gain calculation are exactly opposite. In this case, since transport costs have not changed over these regions, the transport gain will not include the area $KIN$ or $LIM$, but rather will only include the area $QGM^*$. Note, however, that

$$Q_{GM} = Q_{GM}^* + d_{2}Q_1$$

was ten percent of $KQGM$, the scale-direct ratio in (6) would increase ten times.

Other Modifications

The remaining assumptions employed in the single model could likewise be relaxed, but their implications are easy to specify. For example, we assumed linear cost curves and vertical demand schedules. If diminishing returns to economies of scale were introduced, the positive scale effect of the large and expanding center would fall relative to the negative scale effect of the small and contracting center, thereby depressing the relative importance of the scale effect. If downslope demand curves for the commodity were introduced, the demand for $Q$ would increase as the delivered price to the external market fell at the new transport rates, thereby inducing an additional output (and therefore an additional scale) effect into the model. A generalization of the model to allow more realistic functional forms, then, tends to introduce adjustment factors that work in opposite directions. Finally, the use of

<table>
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one commodity does not impose any restrictive conditions. The analysis could always be repeated for any number of commodities transported between any two points and the aggregate scale-to-direct ratio would result from a simple weighted summation.

Conclusions

The model employed above represents a simplified version of various transport projects encountered. The model serves the useful purpose of illustrating the nature and magnitude of the bias that results when scale effects are ignored in estimates of the benefits of transport projects. In general, the results show that the scale effect would not significantly alter the calculation of the transport benefits as long as the elasticity of supply with respect to output is small (namely less than ten percent in absolute magnitude). This result is especially pertinent when the percentage reduction in transport costs is equal to or less than twenty percent. In short, most moderate transport improvements, unless the levels of cost advantages and/or the magnitudes of scale economies of traded goods are unusually large, it would appear that the downward bias introduced by a benefit calculation that excludes the consideration of scale economies would not be significant and therefore should probably be ignored. This conclusion is similar to that found by Mohring and Williamson using a monopolistic model with variable plant sizes and locations.

Important exceptions, however, do occur in our model when economies of scale are significant and when one center of production enjoys a significant comparative advantage over its competitor. In these cases the scale effect was found to be particularly important relative to the direct benefits when the transport project led to significant reductions in the transport rate, say, reductions in the range of twenty to fifty percent. A generalization of the model to allow for the possibility of urban populations or partial transport projects suggested that the scale gain could actually dominate the direct benefits under certain conditions. For transport projects that are characterized by parameters that resemble these cases, a policy planner might be well advised to attempt at least a crude estimation of the scale-to-direct gain along the lines illustrated above.

References

The Foregone Earnings of High School, College, and University Students*

STEPHEN KAGANN

There have been a number of attempts to measure the earnings that high school, college and university students forego. The absence of data on crucial elements of the analyses has induced earlier researchers to develop ingenious techniques to estimate foregone earnings. Now, new Federal data on the income of students and year-round full-time workers permit the development of a reasonably straightforward procedure for the desired estimates. The results suggest that previous attempts to measure earnings foregone by students yielded estimates that were too low. Consequently, the many studies intended to calculate the rate of return to investments in incremental school attendance may have exaggerated these benefits.

Introduction

The largest single cost of providing secondary and higher education in the United States is one that is absent from the national GNP statistics. This omission occurs because the expense is an implicit cost, namely, the potential earnings which students must relinquish when they decide to attend school rather than seek employment.

The earnings that students forego, an opportunity cost in the lexicon of economists, represents a real loss to the individual students who must alter their circumstances relative to their working contemporaries. Society must also consider the loss of production when over 20 million persons are not full-time participants in the labor force because they attend school. The concept of foregone earnings as an opportunity cost retains its validity whether the decision to continue school is based on the desire of the individual student, on informal pressures from family, friends, or society at large, or on laws that require school attendance to a certain age. Only in the first case is a conscious choice among alternatives made by the student. When pressures or coercion are behind the decision, then we say that "society" has determined that income should be foregone in favor of further investment in educated individuals.

In spite of the importance of foregone earnings, only economists concerned with the national investment in human capital and the

*For reasons to be explained, this study will only be concerned with full-time students, of whom there were 200,000 in 1970.