

# The Benefits of India's Rural Roads Program in the Spheres of Goods, Education and Health

Joint Estimation and Decomposition

*Clive Bell*

The World Bank  
South Asia Region  
Transport Unit  
August 2012



## Abstract

All-weather rural roads usually improve not only villagers' terms of trade, but also their educational attainments and health. Obtaining empirical estimates of the benefits generated by the first is straightforward, not so those generated by the others. The object of this paper is to estimate the relative sizes of their respective contributions to total benefits in connection with the all-India rural roads program *Pradhan Mantri Gram Sadak Yojana*, using an overlapping generations model featuring the production and consumption of goods and the formation

of human capital in the presence of both morbidity and mortality. Based on survey evidence from upland Orissa in India and Bangladesh, as well as elements of more usual forms of calibration, the model yields a ratio of commercial to non-commercial benefits of about two-to-one in the first generation, falling to three-to-four in the second. This is broadly consistent with the valuations expressed by respondents in the Orissa survey, who ranked the latter benefits at least on a par with the former.

---

This paper is a product of the Transport Unit, South Asia Region. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at <http://econ.worldbank.org>. The author may be contacted at [clive.bell@urz.uni-heidelberg.de](mailto:clive.bell@urz.uni-heidelberg.de).

*The Policy Research Working Paper Series disseminates the findings of work in progress to encourage the exchange of ideas about development issues. An objective of the series is to get the findings out quickly, even if the presentations are less than fully polished. The papers carry the names of the authors and should be cited accordingly. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent.*

# The Benefits of India's Rural Roads Program in the Spheres of Goods, Education and Health: Joint Estimation and Decomposition

Clive Bell\*

(Appendix by Jochen Laps)

Keywords: Rural roads, transport costs, education, health, India

JEL Classification: E62, O19, O12

Sector Board: Transport

---

\*University of Heidelberg, INF 330, D-69120 Germany. This paper was prepared as part of the documentation for a World Bank loan proposal in connection with PMGSY. The views expressed herein are not, however, necessarily those of the World Bank or its Board.

# 1 Introduction

A new all-weather rural road will bring various benefits to the villagers along its route. As producers, they will enjoy higher net prices for their marketed surpluses; as consumers, they will pay less for urban goods. If there is no school in the village itself, those children who already attend one elsewhere will spend less time traveling to and fro, and those who did not attend earlier may do so now. If there is a village school, it is the teachers themselves who may appear more regularly. Much the same holds for medical treatment. Children and those adults with chronic ailments are more likely to make regular visits to the clinic; and in an emergency, those in need of medical attention will be able to reach the clinic sooner, which may make the difference between life and death.

Measuring the road's effects on these movements of goods and people is, in principle at least, relatively straightforward. Valuing the resulting benefits is another matter altogether. For the new road affects not just the decisions of what to produce and consume in the sphere of what might be called 'textbook goods', but also those having to do with the formation and maintenance of human capital, including life itself. These decisions are not, moreover, readily separable, which calls for their analysis within a unified framework. Yet more is at stake than consistency and rigor. It will be argued that valuing the benefits that arise in connection with more favorable prices of goods, improved educational attainment and lower morbidity involves a common (money) metric which is directly related to effects that are fairly readily measurable – provided families decide not to educate their children fully. In contrast, the benefits of reduced mortality, even if such reductions can be measured with some confidence, do not fit into this convenient scheme of things. The same will hold, moreover, if children are fully educated. How, then, are these benefits to be estimated in practice? A unified framework, in which decisions in the spheres of production, consumption and education are made in a particular environment of morbidity and mortality, provides one way of answering this question. For one can set up the model so that, counter-factually, the road lowers transport costs but nothing else; or, at the other extreme, everything else but transport costs. Granted that the model can be numerically calibrated, one can use the equivalent variation (EV) for each setting, relative to the benchmark of 'no-road', to establish the size of the benefit arising from lower transport costs relative to those arising from other effects. Since estimating the money-metric benefits of lower transport costs is a relatively straightforward task and does not involve the apparatus of a unified model, combining such an estimate with the corresponding contribution

to the total benefit, as yielded by the model, will then yield an estimate of the total benefit that has a substantial empirical anchoring.

The object of this paper is to estimate the *relative* size of the contribution of reduced transport costs, in connection with the all-India rural roads program known as *Pradhan Mantri Gram Sadak Yojana* (PMGSY), a very large scheme that will eventually cover some 170,000 habitations, take at least 20 years to implement and cost in excess of US\$40 billion (World Bank, 2010). The unified framework employed for this purpose is the overlapping generations (OLG) model of Bell, Bruhns and Gersbach (2006), substantially extended so as to cover transport costs and morbidity. Important elements of the empirical basis for this application are supplied by an analysis of a survey of some 240 households drawn from 30 villages lying in the upland – and poor – region of Orissa (Bell and van Dillen, 2012) and two large surveys in Bangladesh (Khandker *et al.*, 2009). There is also an indirect check, in the form of completely independent estimates of the so-called value of a statistical life provided by Lui *et al.* (1997) and Simon *et al.* (1999).

The plan of the paper is as follows. The model is set out and analyzed in Section 2, the essential difficulty with valuing the benefits arising from effects other than those of lower transport costs being addressed in Section 2.3. The numerical set-up follows in Section 3, which is divided up into subsections dealing with functional forms, parameter values and calibration under perfect foresight. This is the basis for the exact welfare analysis in Section 4, treating in sequence the benchmark of ‘no-road’, the world with the road and the contribution of lower transport costs to the whole resulting benefit. The conclusions are drawn together in Section 5.

## 2 The Model

The basis is the model of Bell, Bruhns and Gersbach (2006), which deals with human capital formation and growth when there is premature adult mortality. To summarize, an extended family comprises three overlapping generations, with all surviving adults caring for all related children in each period, which stretches over a generation.<sup>1</sup> The young adults are assumed to decide how current resources are to be allocated between consumption and the children’s education. The level of current resources available to

---

<sup>1</sup>This arrangement is admittedly a rather idealized description of the social structure even in Kenya, let alone in rural India, but the pooling of the risks of premature mortality among the adults greatly simplifies the analysis.

the family is largely determined by the level of the parents' human capital and their survival rate, but the children themselves can also work instead of attending school. At the end of each period, some young adults die prematurely, all old adults die, and the children are on the point of becoming young adults.

How much of childhood, if any, is spent at school depends not only on the family's available resources, but also on three further factors. First, there is the parents' desire to provide for their old age and their children's future, motives which express themselves in the parents' willingness to forego some current consumption in favour of investment in their children's schooling, and hence of the children's human capital when they attain adulthood in the next period. Second, there is the efficiency with which schooling is transformed into human capital, which arguably depends on the quality of the school system and child-rearing within the family, whereby the latter ought to improve with the parents' human capital. Third, the returns to the investment in any child will be effectively destroyed if that child dies prematurely in adulthood. This implies that the expected returns to education depend on parents' (subjective) assessments of the probability that their children will meet an untimely death.

For present purposes, we need to extend this framework in two ways. First, the transportation of goods and persons must be brought into the picture. Instead of the aggregate consumption good in Bell, Bruhns and Gersbach (2006), there are now two consumption goods, one of which the household produces; the other is an 'urban' good, which the household can obtain only through exchange. The resulting trade necessarily involves transportation. The same holds for education and health, insofar as the children and their teachers must travel to school and the sick to a clinic, which may lie some distance off and, in the absence of an all-weather road, be inaccessible at times. Second, we introduce morbidity, which, as formulated below, reduces individuals' capacities to go about their daily business.

## 2.1 Human capital and output

We begin by introducing some notation.

$N_t^a$ : the number of individuals in the age-group  $a$  ( $= 1, 2, 3$ ) in period  $t$ ,

$\lambda_t^a$ : the human capital possessed by an adult in age-group  $a$  ( $= 2, 3$ ),

$\gamma$ : the human capital of a school-age child,

$\alpha_t$ : the output produced by a unit of human capital input in year  $t$ ,

$e_t$ : the proportion of their school-age years actually spent in school by the cohort of children ( $a = 1$ ) in period  $t$ .

Human capital is formed through a process that involves the adults' human capital and the educational technology. The human capital attained by a child on becoming an adult in period  $t + 1$  depends, in general, on the numbers and human capital of the adults, the level of schooling that child received, and the number of siblings of school-going age, who were presumably competing for the adults' attention, care and support – all in the previous period. Formally,

$$\lambda_{t+1}^2 = \Phi(e_t, \boldsymbol{\lambda}_t, \mathbf{N}_t), \quad (1)$$

where  $\boldsymbol{\lambda}_t = (\lambda_t^2, \lambda_t^3)$  and  $\mathbf{N}_t = (N_t^1, N_t^2, N_t^3)$  and  $\Phi$  is increasing in all its arguments, except for  $N_t^1$ .

Simplifying with the application in mind, let  $\Phi$  be multiplicatively separable in: (i) the educational technology, which involves only  $e_t$ ; (ii) the average level of the adults' human capital; and (iii) the degree of competition among siblings. This implies that formal education and the adults' human capital are complements in producing the children's human capital, which is intuitively plausible.<sup>2</sup> Parents in rural India have most of their children when they are in their twenties, and in their thirties, they are busy rearing them to adulthood. Normalizing the structure to a representative couple within the extended family, these assumptions yield the following specialization of (1):

$$\lambda_{t+1}^2 = f_t(e_t) \cdot \frac{2(N_t^2 \lambda_t^2 + N_t^3 \lambda_t^3)}{N_t^2 + N_t^3} \cdot \psi\left(\frac{N_t^1}{N_t^2 + N_t^3}\right) + 1, \quad (2)$$

where  $f_t(\cdot)$  represents the educational technology, whose efficiency may vary with time, and the function  $\psi(\cdot)$  the effects of competition among siblings for their parents' time and attention. These functions are assumed to have the following properties:  $f_t(\cdot)$  is continuous and increasing  $\forall e_t \in [0, 1)$ , with  $f_t(0) = 0$ ; and  $\psi(\cdot)$  is continuous and decreasing in the number of children per adult, and goes to zero as that number becomes arbitrarily large. The assumption  $f_t(0) = 0$  implies that a child who receives no schooling will attain only some basic level of human capital, which, without loss of generality, may be normalized to unity – hence the '1' on the RHS of (2). The assumption that  $\psi(\cdot)$  is a decreasing function implies that, *cet. par.*, an increase in mortality among parents that outweighs any reduction in fertility will hinder the formation of human

---

<sup>2</sup>Becker, Murphy and Tamura (1990) and Ehrlich and Lui (1991) pioneered the approach based on the direct transmission of potential productivity from parent to child.

capital among their children. Let there be no depreciation of human capital.

The difference equation (2) governs the system's dynamics. A brief remark will suffice on the asymptotic behaviour of  $\lambda_t^2$  when there is full education. Observe that under stationary technological and demographic conditions, (2) may be written as

$$\lambda_{t+1}^2 = 2f(e_t)(a_2\lambda_t^2 + a_3\lambda_{t-1}^2) + 1,$$

where  $a_2$  and  $a_3$  are constants and  $\lambda_{t-1}^2 = \lambda_t^3$ . Suppose  $e_t = 1 \forall t$ , so that the relevant characteristic root is  $a_2[1 + \sqrt{(1 + 2a_3/(a_2^2 f(1)))}]f(1)$ . Then, starting from a sufficiently large value of the parents' combined human capital, when they would choose  $e_t = 1$ , unbounded growth of  $\lambda_t^2$  is possible if  $a_2[1 + \sqrt{(1 + 2a_3/(a_2^2 f(1)))}]f(1) \geq 1$ , and the inter-generational growth rate then approaches

$$g^* \equiv a_2[1 + \sqrt{(1 + 2a_3/(a_2^2 f(1)))}]f(1) - 1, \quad (3)$$

from above. If, however,  $1 > 2(a_2 + a_3)f(1)$ ,  $\lambda_t^2$  will approach the stationary value  $1/[1 - 2(a_2 + a_3)f(1)]$ . It should be remarked that if  $e_t$  is restricted below unity, to  $\bar{e}_t$  say, then the latter value will replace unity as the argument of  $f(\cdot)$  in the above expressions. This will be important when analysing the long-run effects of morbidity, travelling to school and involuntary absences in Sections 3 and 4.

The household produces a single consumption good (good 1) solely by means of labor, measured in efficiency units, under constant returns to scale. A natural normalization is that a healthy adult who possesses human capital in the amount  $\lambda_t^a$  is endowed with  $\lambda_t^a$  efficiency units of labor, which he or she is assumed to supply completely inelastically. To accommodate sickness and injury, denote the fraction of each period that a surviving adult spends in disability by  $d_t^a$  ( $a = 2, 3$ ). Children, too, suffer ailments, which reduce the effective time left for schooling and work. Each child supplies  $(1 - d_t^1 - (1 + \tau)e_t)\gamma$  efficiency units of labor when it spends  $e_t$  units of time in school and, unavoidably,  $\tau e_t$  units of time travelling to and from school, whereby  $\gamma \in (0, 1)$ , i.e., a full-time working child is less productive than an uneducated adult. The household therefore produces

$$y_{1t} = \alpha_t [N_t^1(1 - d_t^1 - (1 + \tau)e_t)\gamma + (1 - d_t^2)N_t^2\lambda_t^2 + (1 - d_t^3)N_t^3\lambda_t^3] \quad (4)$$

units of good 1 in period  $t$ .



## 2.2 The family's preferences and decisions

Some additional notation is needed.

$x_{it}$ : the consumption of good  $i$  ( $= 1, 2$ ) by each young adult,

$\beta$ : the proportion of a young adult's consumption received by each child,

$\rho$ : the proportion of a young adult's consumption received by each old adult,

$\sigma_t$ : the direct costs per child of each unit of full-time schooling,

$n_t$ : the number of children born to a representative couple who survive to school age in period  $t$ ,

${}_xq_a$ : the probability that an individual aged  $a$  will die before reaching the age of  $a + x$ ,

$q_t$ : the probability that a young adult in period  $t$  will die before reaching the third phase of life.<sup>3</sup>

The parameters  $\beta$  and  $\rho$  are viewed as binding by all concerned through a social norm and they are enforced by appropriate social sanctions.

The extended family's expenditure-income identity involves, in principle, outlays on the two consumption goods, health care and education, where the latter include both the direct expenditures and the opportunity costs of the pupils' time. In what follows, we resort to the drastic simplification that there are no expenditures on getting to the clinic and being treated: mortality and morbidity rates are set exogenously, at levels that depend on the availability or otherwise of an all-weather road. This is not merely simplification in the interests of making the analysis more tractable. For the relationship between choosing treatment and the experience of disability over the whole stretch of a generation is not only difficult to model, but is also not well-established empirically: for example, better access to a clinic may induce timelier and heavier outlays on treating an acute ailment, and so save outlays on undoing even more damage later, should the condition go untreated at the outset.

It will be convenient to normalize the budget identity by the number of young adults. The said identity may then be written as:

$$P_t(\beta, \rho) \cdot \mathbf{p}_t \cdot \mathbf{x}_t + Q_t(\alpha_t, \gamma, \sigma_t, \tau) \cdot e_t \equiv p_{1t}\alpha_t \cdot (\Lambda_t + N_t^1(1 - d_t^1)\gamma)/N_t^2, \quad (5)$$

---

<sup>3</sup>In the present structure, this statistic corresponds to  ${}_{20}q_{20}$ , the probability that an individual will die before 40, conditional on surviving until 20.

where the household faces the price vector  $\mathbf{p}_t$  for the two consumption goods and

$$\Lambda_t \equiv N_t^2(1 - d_t^2)\lambda_t^2 + N_t^3(1 - d_t^3)\lambda_t^3 \quad (6)$$

is the adults' aggregate supply of efficiency units of labor. The term

$$P_t(\beta, \rho) \equiv (1 + (\rho N_t^3 + \beta N_t^1)/N_t^2) \quad (7)$$

expresses the effect of the family's demographic structure on the 'price' of the consumption bundle  $\mathbf{x}_t$  relative to education. Analogously, the 'price' of a unit of full education ( $e_t = 1$ ) is

$$Q_t \equiv (p_{1t}\alpha_t(1 + \tau)\gamma + \sigma_t)N_t^1/N_t^2. \quad (8)$$

The RHS of (5) is the level of (normalized) full income in period  $t$ . In this connection, observe that  $N_t^1$ ,  $N_t^2$  and  $N_t^3$  are related as follows:

$$N_t^1 = n_t N_t^2 / 2, \quad (9)$$

$$N_t^2 = n_{t-1} N_{t-1}^2 / 2, \quad (10)$$

$$N_t^3 = (1 - q_{t-1}) N_{t-1}^2. \quad (11)$$

The young adults' preferences are, in principle at least, defined over the following: the levels of consumption in young adulthood and old age,  $\mathbf{x}_t$  and  $\rho\mathbf{x}_{t+1}$ , respectively, and the human capital attained by their school-age children on attaining full adulthood ( $\lambda_{t+1}^2$ ), which they may appreciate in both phases of their own lives. Investment in the children's education therefore produces two kinds of pay-offs, one altruistic, as expressed by the value directly placed on  $\lambda_{t+1}^2$ , and the other selfish, inasmuch as an increase in  $\lambda_{t+1}^2$  will also lead to an increase in  $\rho\mathbf{x}_{t+1}$  under the said social rules.

Although the pooling arrangement implicit in the extended family structure eliminates the risk that orphaned children will be left to fend for themselves, others remain. A young adult still faces uncertainty about whether he or she will actually survive into the last phase of life, and whether his or her children will do likewise, conditional on their reaching adulthood in their turn. The incidence of morbidity is uncertain at the level of the individual, though if the extended family is large enough, its realized levels of morbidity will differ little from the population rates. There is also uncertainty about future demographic developments, which will influence the realized level of  $\rho\mathbf{x}_{t+1}$ .

At the start of period  $t$ , young adults choose like partners. Each couple produces  $n_t$

children, and then draws up a plan for current consumption and investment in the children's education based on the family's resources and expectations about its members' state of health and other relevant variables in the coming and future periods. Given such assortative mating, the pair will agree wholly on what is to be done. Appealing to the law of large numbers in order to rid the system of any uncertainty about the realized levels of morbidity in period  $t$ , so that full income in that period is non-stochastic, let the preferences of a young adult at time  $t$  be represented as follows:

$$E_t U = b_1 u(\mathbf{x}_t) + b_2(1 - q_t) E_t [u(\rho \mathbf{x}_{t+1})] + E_t [(1 - q_{t+1})] \cdot n_t \phi(\lambda_{t+1}^2), \quad (12)$$

where goods 1 and 2 are private goods in consumption, but the children's attainment of human capital is a public one within the union. It should be noted, first, that no account has been taken of the pain and suffering associated with morbidity, even though its level may change exogenously; second, that the 'pay-offs' in the event that the parent should die prematurely (with probability  $q_t$ ), or that any of the children, in their turn, should die prematurely in adulthood (each with probability  $q_{t+1}$ ), have been normalized to zero; and third, that conditional on surviving into old age at  $t + 1$ , the associated level of consumption,  $\rho \mathbf{x}_{t+1}$ , is also a random variable viewed at time  $t$ , for its level depends on a whole variety of future economic and demographic developments. Finally, observe also that the parents' altruistic motive makes itself felt only when they themselves are young and actually make the sacrifices, whereby  $\lambda_{t+1}^2$  is non-stochastic by virtue of  $e_t$  being non-stochastic.

These adults take all features of the environment in periods  $t$  and  $t + 1$  as parametrically given. It will be helpful to distinguish between what they know and what they must forecast. At the time of decision, the current endowment and environment are described by the vector

$$\mathbf{Z}_t \equiv (\mathbf{N}_t, n_t, \boldsymbol{\lambda}_t, P_t, Q_t, \mathbf{p}_t, \tau, \alpha_t, q_t, \mathbf{d}_t). \quad (13)$$

This is assumed to be known.<sup>4</sup> What is unknown are the (future) realizations of  $\mathbf{x}_{t+1}$  and  $q_{t+1}$ . Under the social norm expressed by  $\rho$ , the parents at  $t$  must form expectations about how their surviving children will allocate full income in period  $t + 1$ , a decision that depends, not only on  $\mathbf{Z}_{t+1}$ , which will have been revealed at that time, but also on all future constellations thereafter, to the extent that these influence  $(\mathbf{x}_{t+1}, e_{t+1})$ .

---

<sup>4</sup>It can be argued that there is uncertainty about  $q_t$  at the point of decision at time  $t$ , the (invisible) unit period being rather long. This possibility is addressed below.

For simplicity, all individuals' forecasts of all elements of the future environment are assumed to be point estimates, so that whilst there is uncertainty about an individual's personal fate, there is none about the future mortality profile itself or future fertility. Indeed, we go farther down this path, and assume not only that all individuals share the same forecasts of  $\{\mathbf{Z}_{t+1}\}_{t=1}^{t=\infty}$ , but also that these forecasts are unerring: that is to say, there is perfect foresight about everything – with the vital exception of whether a particular individual will die prematurely. Under this assumption,  $\rho \mathbf{x}_{t+1}$  becomes non-stochastic, conditional on surviving into old age at time  $t + 1$ , so that (12) may be written

$$E_t U = b_1 u(\mathbf{x}_t) + b_2 (1 - q_t) u(\rho \mathbf{x}_{t+1}^0) + (1 - q_{t+1}) \cdot n_t \phi(\lambda_{t+1}^2(e_t)), \quad (14)$$

where the superscript '0' denotes the optimal choice of those making decisions at time  $t + 1$ , which their parents forecast unerringly at  $t$ . The functions  $u$  and  $\phi$  are assumed to be strictly concave.

A young adult's decision problem therefore takes the following form:

$$\max_{(\mathbf{x}_t, e_t | \{\mathbf{Z}_{t+t'}\}_{t'=0}^{t'=\infty})} E_t U \quad \text{s.t. } \mathbf{x}_t \geq \mathbf{0}, e_t \in [0, (1 - d_t^1)/(1 + \tau)], (2), (5). \quad (15)$$

If  $f_t^1(\cdot)$  is concave,  $E_t U(\cdot)$  will be strictly concave in  $(\mathbf{x}_t, e_t)$ . Hence, problem (15) has a unique solution and the first-order necessary conditions are also sufficient. Observe that the optimum always involves  $\mathbf{x}_t > \mathbf{0}$ . The corner solution in which the children are not educated at all can also be ruled out when  $f(\cdot)$  satisfies the lower Inada condition, since  $\partial \lambda_{t+1}^2 / \partial e_t$  is then unbounded at  $e_t = 0$ ; but this condition will not be imposed.

## 2.3 Comparative statics

The associated Lagrangian is, omitting the non-negativity constraints for brevity,

$$\begin{aligned} \mathcal{L} = & b_1 u(\mathbf{x}_t) + b_2 (1 - q_t) u(\rho \mathbf{x}_{t+1}^0) + (1 - q_{t+1}) \cdot n_t \phi(\lambda_{t+1}^2(e_t)) \\ & + \mu [p_{1t} \alpha_t \cdot (\Lambda_t + N_t^1 (1 - d_t^1) \gamma) / N_t^2 - P_t(\beta, \rho) \cdot \mathbf{p}_t \cdot \mathbf{x}_t - Q_t(\alpha_t, \gamma, \sigma_t) \cdot e_t]. \quad (16) \end{aligned}$$

The Envelope Theorem yields the following results, all of which accord with elementary intuition. Where the movement of goods and school children is concerned, we have

$$\frac{\partial E_t U^0}{\partial p_{1t}} = \mu [\alpha_t \cdot (\Lambda_t + N_t^1(1 - d_t^1)\gamma)/N_t^2 - P_t(\beta, \rho) \cdot x_{1t} - (\alpha_t(1 + \tau)\gamma N_t^1/N_t^2)e_t] > 0, \quad (17)$$

and

$$\frac{\partial E_t U^0}{\partial p_{2t}} = -\mu P_t(\beta, \rho) \cdot x_{2t} < 0, \quad (18)$$

by virtue of the fact that the household is a net seller of good 1 and a net buyer of good 2, and  $e_t \leq (1 - d_t^1)/(1 + \tau)$ . An increase in the travel-time to school is likewise damaging. Denoting by  $\nu$  the multiplier associated with  $e_t \leq (1 - d_t^1)/(1 + \tau) \equiv \bar{e}_t$ ,

$$\frac{\partial E_t U^0}{\partial \tau} = -\mu p_{1t} \alpha_t \gamma (N_t^1/N_t^2) e_t - \nu (1 - d_t^1)/(1 + \tau)^2. \quad (19)$$

Morbidity reduces not only the family's productive endowments, pain and suffering having been ruled out by assumption, but also  $\bar{e}_t$ :

$$\frac{\partial E_t U^0}{\partial d_t^1} = -\mu p_{1t} \alpha_t \gamma \cdot (N_t^1/N_t^2) - \nu/(1 + \tau), \quad (20)$$

$$\frac{\partial E_t U^0}{\partial d_t^2} = -\mu p_{1t} \alpha_t \cdot \lambda_t^2, \quad (21)$$

$$\frac{\partial E_t U^0}{\partial d_t^3} = -\mu p_{1t} \alpha_t \cdot (N_t^3/N_t^2) \lambda_t^3. \quad (22)$$

Turning at last to mortality, we begin by recalling (11); so that  $q_t$  exerts an influence on  $E_t U$ , not only directly, but also on the feasible set in period  $t + 1$ , and hence on  $\mathbf{x}_{t+1}^0$ . We have

$$\frac{\partial E_t U^0}{\partial q_t} = -b_2 u(\rho \mathbf{x}_{t+1}^0) + b_2 (1 - q_t) \nabla u(\rho \mathbf{x}_{t+1}^0) \cdot \left( \rho \frac{\partial \mathbf{x}_{t+1}^0}{\partial q_t} \right); \quad (23)$$

and

$$\frac{\partial E_t U^0}{\partial q_{t+1}} = b_2 (1 - q_t) \cdot \nabla u(\rho \mathbf{x}_{t+1}^0) \cdot \left( \rho \frac{\partial \mathbf{x}_{t+1}^0}{\partial q_{t+1}} \right) - n_t \phi(\lambda_{t+1}^2(e_t)), \quad (24)$$

which reflects the fact that an increase in premature mortality among the children on reaching adulthood will also affect the parents' consumption in old age, should they survive to enjoy it. In this connection, note that an increase in  $q_{t+1}$  may well induce an *increase* in  $\mathbf{x}_{t+1}^0$ , since higher premature mortality in any period makes old-age provision for the next less attractive.

### 3 Setting up the System Numerically

The benefits flowing from an all-weather road stem from more favorable prices facing the household as producer and consumer, from reduced time for the children to go to and from school, and from lower morbidity and mortality due to timelier treatment. Under the above assumptions, it is seen from (17) - (22) that, with the exception of reduced mortality, sufficiently small changes in each of these features of the ‘environment’ yield benefits that, in money-metric utility, are equal to the gains or savings calculated at the allocation ruling before the said change and valued at the corresponding opportunity cost.<sup>5</sup> Inspection of (23) and (24), however, reveals that there is no such ready simplification where mortality is concerned; for the sub-utility functions  $u$  and  $\phi$  appear explicitly, as does the next bundle,  $\mathbf{x}_{t+1}^0$ , in the perfect-foresight sequence  $\{\mathbf{x}_t^0\}_{t=0}^{t=\infty}$ . In order to obtain some feel for the size of the value placed on reduced mortality relative to that of other benefits, a resort to some numerical examples is unavoidable. This task involves the construction of the whole perfect-foresight sequence.

#### 3.1 Functional forms

There is no hope of estimating more than a tiny part of this system econometrically; and even ‘calibration’ for the system as a whole is ruled out for want of suitable data. The approach, therefore, is to choose functional forms that are both tractable and plausible, if only through common usage in other contexts, and then constellations of associated parameter values such that certain key magnitudes correspond to what are called the ‘stylized facts’.<sup>6</sup>

1. *Technologies.* Let  $f_t(e_t) = z_t e_t \forall t$ , where  $z_t$  represents an inter-generational transmission factor, which reflects the quality of both child-rearing and the school system. This limiting form is certainly the simplest, and it causes no technical problems in view of the assumption that  $\phi$  is strictly concave (see below). The absence of diminishing returns does not seem especially odd when one reflects on the need for children to spend some years in school before they have mastered the three R’s, which form the basis of all other acquired abilities involving literacy. The great majority of school-children in

---

<sup>5</sup>Observe that if  $\nu = 0$ , each of these expressions is scaled by the Lagrange multiplier  $\mu$ . As it turns out, this simplification is lost after period 1, when  $\nu > 0$ ; so that the whole apparatus is also needed in connection with changes in trip-time and morbidity.

<sup>6</sup>As Solow once wrote in the original connection with the character of growth in industrialized countries in the decades following WWII, they are certainly stylized, but whether they are facts is another matter.

India's villages now receive some education, moreover, so that this form of  $f(e_t)$  can also be thought of as applying over the relevant range up to a full education. Turning to competition among siblings, rather little is known about its effects on human capital formation, so we adopt the agnostic position that  $\psi = 1 \forall \mathbf{N}_t$ . With these choices, (2) specializes to

$$\lambda_{t+1}^2 = 2z_t \cdot e_t \cdot \frac{N_t^2 \lambda_t^2 + N_t^3 \lambda_t^3}{N_t^2 + N_t^3} + 1. \quad (25)$$

*2. Preferences.* In the macroeconomics literature, especially the empirical kind, the logarithm tends to hold sway. There is usually, however, an aggregate consumption good. For present purposes, therefore, form the Cobb-Douglas aggregate  $x_{1t}^a \cdot x_{2t}^{1-a}$  ( $0 < a < 1$ ), which is homogeneous of degree one in  $\mathbf{x}_t$ . Applying the logarithm to this index of consumption, we obtain

$$u(\mathbf{x}_t) = a \ln x_{1t} + (1 - a) \ln x_{2t} \quad \forall t.$$

There is much less guidance to be had about  $\phi(\cdot)$ . In their study of Kenya over the historical period 1950-1990, Bell, Bruhns and Gersbach (2006) employed the logarithmic form for  $u$ , but the data resisted their attempts to impose this on  $\phi$ . More curvature was needed, and successful calibration was achieved with the iso-elastic form

$$\phi(\lambda_{t+1}^2) = 1 - (\lambda_{t+1}^2)^{-\eta} / \eta,$$

whereby the value of  $\eta$  lay in the range 0.35 – 0.65, with a clustering around 0.5. This form will be adopted here, too. The associated values of  $\eta$  will provide a useful point of departure.

### 3.2 Parameters and the values of exogenous variables

We need some starting values, namely, for period  $t = 1$ . In view of India's demographic history and the prevailing state of affairs in rural areas, let  $\mathbf{N}_1 = (3, 2, 0.75)$ , with  $n_1 = 3.5$ . There is much illiteracy among the old, but less among their children, who are today's parents. Rising productivity over the past generation also suggests that  $\lambda_1^2$  is substantially larger than  $\lambda_1^1$ . Hence, let  $\boldsymbol{\lambda}_1 = (1.7, 1.2)$ .

Given the numerous parameters, and corresponding degree of under-identification, there is no call for great precision everywhere. Let  $\gamma = 0.65$  and the social norms demand  $\beta = 0.6$  and  $\rho = 0.8$ . Households are still rather poor, so their taste for good

1 should be at least as strong as that for good 2: accordingly, let  $a = 0.5$ . Without loss of generality, set the prices of both goods in the town at unity in all periods. A survey of 30 villages in upland Orissa for the year 2009-10 (Bell and van Dillen, 2012) yields the finding that in the absence of an all-weather road, the unit transport costs for paddy, the main crop, were a bit less than 0.1, but those for other commercial crops somewhat higher. Applying the same to fertilizers, seeds and other goods bought in, households in such villages then face the price vector  $\mathbf{p}_t = (0.9, 1.1) \forall t$ . As for the trip to school, the great majority of India's villages have a primary one of their own; but only a small minority have a secondary or high school, and in the absence of an all-weather road, the daily round-trip time can be rather long. The averages for primary and secondary school pupils in the Orissa villages lacking such a road were 23 and 76 minutes, respectively. Allowing, say, twelve hours for sleeping, eating and bathing at home, and taking into account the higher opportunity costs of older children's time, let  $\tau = 0.08$ . The direct costs of state schooling are surely modest: recalling (8), let  $\sigma_t$  be 0.15 times the opportunity cost factor  $p_{1t}\alpha_t(1 + \tau)\gamma$ , whereby  $\alpha_t$  has yet to be determined. For the moment, we also defer discussion of the inter-temporal taste parameters  $b_1$  and  $b_2$ .

Coming by estimates of premature adult mortality is a far easier task than that of morbidity. In a setting of three overlapping generations, each generation corresponds to about 20 years, the age at which full adulthood is attained. The rate  $q_t$  therefore corresponds to  ${}_{20}q_{20}$ , the probability that an individual will die before reaching 40, conditional on reaching 20. For India in 2005, WHO (2007) gives  ${}_{20}q_{20} = 0.065$  and  ${}_{30}q_{20} = 0.123$ . Something closer to the latter is suited to our present purposes, first, to allow for some mortality in the first part of old age, which the rigid time structure of the model rules out, and secondly, to reflect higher mortality among rural middle-aged adults than the all-India average. Hence, let  $q_1 = 0.125$ . If history and international experience are any guides, this is sure to fall over the coming generation, PMGSY or no. It does not seem too much to hope that India will do as well then as China does now, so let  $q_2 = 0.053$ . Where morbidity and disability are concerned, school-age children typically suffer less sickness than their parents, who, in turn, are in better health than their aged parents. The findings from the Orissa survey confirm as much, the average number of days of reported sickness being 5.6 a year, though the contribution of chronic ailments may not have been properly covered. It is also possible that sickness was interpreted as being too unwell to go about the usual daily business at all, as opposed to being in a state of diminished capacity to do so. Thus, the vector  $\mathbf{d}_1 = (0.02, 0.04, 0.08)$  represents a rather speculative stab at an estimate for period 1. Since



it is easier to ward off premature death than morbidity, the associated improvement to  $\mathbf{d}_2 = (0.015, 0.03, 0.06)$  in period 2 is a bit less dramatic than that in mortality.

### 3.3 Setting up the sequence under perfect foresight

The system must be set up in such a way that it satisfies two requirements. First, the household must choose a plan that is in keeping with what we observe in the present. The key variable here is the level of investment in education,  $e_1$ . Children in India's rural areas typically start school at 6 years of age and complete about 6 years of schooling on average. Hence, with up to 12 years of schooling available, and noting that morbidity reduces the endowment of productive time, the model must be set up so as to yield  $(1 + \tau)e_1^0 = (6/12)(1 - d_1^1)$ . A further adjustment is needed for the number of days lost due to bad weather, especially in the monsoon. The Orissa survey yields an estimated 8.6 and 9.4 days a year, on average, for primary- and secondary-school children, respectively, involuntary absences that were mainly attributable to their teachers' failure to arrive (Bell and van Dillen, 2011). Assuming a school year of 180 days, the required condition becomes  $(1 + \tau)e_1^0 = (1 - 9/180)(6/12)(1 - d_1^1) = (19/40)(1 - d_1^1)$ , where  $\tau = 0.08$  and  $d_1^1 = 0.02$ .

Secondly, the whole sequence must be anchored to some plausible configuration in the future. In this connection, there is much talk of meeting the so-called Millennium Development Goals by 2015, and suchlike. Let us suppose, therefore, that a full education for all is attainable within one complete generation, where the definition of a 'full education' must make a full allowance for the claims on a child's time made by illness, traveling to school and other involuntary absences. That is to say, the model must be set up such that parents in period 2 do choose  $e_2^0 = \bar{e}_2 = 0.95(1 - d_2^1)/(1 + \tau)$ . If the general environment described by  $\mathbf{Z}_t$  does not deteriorate thereafter, it will then follow that  $e_t^0 = \bar{e}_t = 0.95(1 - d_t^1)/(1 + \tau) \forall t \geq 3$ . For once  $e_t^0 = 0.95(1 - d_t^1)/(1 + \tau)$  is attained, the young adults in that period can then be certain that all future generations will continue this policy, with its corresponding effects on their consumption in old age, as formulated in (15). The desired anchoring of the system will have been accomplished.

The simplest way of ensuring all this where  $\mathbf{Z}_t$  is concerned is to impose stationarity from period 2 onwards. On the assumption that fertility will fall to replacement levels by 2030, and allowing for premature mortality among adults, let  $\mathbf{N}_t = (2, 2, 1.5) \forall t \geq 2$ . Also stationary are prices, tastes and costs, a road being built, if at all, at the start

of period 1 (see below). Recalling the discussion of mortality and morbidity in Section 3.2, we also have  $q_t = 0.053$  and  $\mathbf{d}_t = (0.015, 0.03, 0.06) \forall t \geq 2$ .

The final step is to choose the productivity parameters  $z_t$  and  $\alpha$  and the intertemporal taste parameters  $b_1$  and  $b_2$  so as to yield  $e_2^0 = 0.95(1 - 0.015)/1.08 = 0.866$  with as little to spare as possible. With the exception of  $z_t$ , this must be accomplished by trial and error as part of the process of computation. The only prior restriction is that with pure impatience for consumption,  $b_1 > b_2$ . Since premature mortality already appears in connection with preferences over dated consumption, the pure discount rate arguably should not greatly exceed 15 percent per generation of 20 years.

One can arrive at an appropriate value of  $z$  by imposing the assumption that individual productivity,  $\lambda_t$ , will grow without limit if, after some point, all generations are fully educated. As noted in Section 2.1, by choosing a sufficiently productive technology  $f(e_t)$  and otherwise setting up the system so that  $e_t^0 = \bar{e}_t \forall t \geq 2$ , where  $e_t^0 = \bar{e}_t$  is sufficiently close to 1, we ensure that  $\lambda_t^2$  will indeed grow without bound. Recall from (3) that the relevant characteristic root when the upper limit on  $e_t$  is unity is  $1 + g^*$ . Reducing this upper limit to  $\bar{e} = 0.866$  yields the root  $a_2[1 + \sqrt{(1 + 2a_3/a_2^2)f(0.866)}]f(0.866)$ , where  $f(e_t) = z_t e_t$ ,  $a_2 = 2/3.5$  and  $a_3 = 1.5/3.5$ . Let  $z_t = 0.85 \forall t$ , which implies that output per head will grow at the rate of 41.3 percent per generation, or 1.74 percent a year. This seems defensible for an horizon many generations off.

## 4 A New Road: Exact Welfare Measures

Imagine two islands, each inhabited by a representative extended family. The first is characterized by the constellation of numerical values set out in Section 3. The second is identical, except for the happy event that a road is provided free of charge at the very start of period 1. As a result, unit transport costs, travel-times, morbidity and mortality all become lower than those on island 1. In this more benign environment, it is not only certain that  $e_t^0 > 0.866 \forall t \geq 2$ , but also highly likely that  $e_1^0$  will be higher than on island 1. The latter being so, the path  $\{\lambda_t^2\}_{t=2}^\infty$  will lie everywhere above its counterpart on island 1. The two paths will, moreover, exhibit different asymptotic rates of growth, even though they share the common value of  $z_t$ . This ‘growth-effect’ stems from lower morbidity, reduced round-trip times to school and fewer involuntary absences, all of which bring the upper limit  $\bar{e}_t$  closer to unity – as long as the road does not fall into utter disrepair. If it were to do so at the end of period 1, for example,  $e_t^0 = 0.866 \forall t \geq 2$  would still be ensured thereafter, under the hypothesis that it holds

on island 1, which will have no road in any period. Even in the face of such neglect, therefore, there would remain a ‘level-effect’.

Island 1, therefore, provides the benchmark for the following thought-experiment. At the very start of period 1, the inhabitants of island 2 are given the choice between having the road and making do with the conditions ruling on island 1, but receiving a lump-sum payment instead. If the latter sum is such that they are indifferent between these two alternatives, we will have found the equivalent variation (EV) corresponding to the provision of the road, as assessed by the young adults in period 1 on both islands. The road will, of course, yield further benefits in later periods, even if it falls into utter disrepair at the end of period 1. For the level-effect alluded to above will come into play, and to the associated increase in the family’s full income there will correspond an EV for that generation of young adults. In what follows, however, we will confine our attention to the EV for young adults in periods 1 and 2, leaving the task of estimating the whole sequence thereof to another paper.

#### 4.1 The benchmark: No road

Recalling Section 3.3, the task here is to choose  $\alpha$ ,  $b_1$  and  $b_2$  so that  $e_2^0 = 0.866$  is barely attained. It is easily seen that the whole sequence  $\{\lambda_t^2\}_{t=1}^\infty$  can be derived on the hypothesis that  $e_t^0 = 0.866 \forall t \geq 2$  without any reference to  $\alpha$ ,  $b_1$  and  $b_2$ . The parameter values, the initial conditions and (25) yield

$$\lambda_2^2 = 2 \times 0.85 \cdot \frac{(19/40)(1 - 0.02)}{1.08} \cdot \frac{2 \times 1.7 + 0.75 \times 1.2}{2 + 0.75} + 1 = 2.1457.$$

Continued recursion using  $\{N_t\}_{t=2}^\infty$  yields

$$\lambda_3^2 = 2 \times 0.85 \times 0.866 \cdot \frac{2 \times 2.1457 + 1.5 \times 1.7}{2 + 1.5} + 1 = 3.8791,$$

$$\lambda_4^2 = 2 \times 0.85 \times 0.866 \cdot \frac{2 \times 3.8791 + 1.5 \times 2.1457}{2 + 1.5} + 1 = 5.6195,$$

and so forth.

Having thus determined that  $\lambda_2^2 = 2.1457$ , the hypothesis  $e_2^0 = 0.866$  leaves the household in period 1 with almost all the information needed to derive  $\mathbf{p}_2 \cdot \mathbf{x}_2^0$  from (5), whereupon  $\mathbf{x}_2^0$  would follow from the assumption that the sub-utility function  $u$  is (transformed) Cobb-Douglas. The missing element is the value of  $\alpha$ . Moving back to calibration, therefore, it follows that by hazarding a guess at  $\alpha$ , we are then left to

find a pair  $(b_1, b_2)$ , with  $b_2 \approx 0.85b_1$ , such that the solution to problem (15) in period 1 indeed involves  $e_1^0 = (19/20)(6/12)(1 - 0.02)/1.08$ , whereby  $\alpha$  may be varied until the desired result is obtained. Mindful of the need to fulfill the hypothesis  $e_2^0 = 0.866$ , but not too comfortably, some experimenting yielded  $\alpha = 5$ , albeit with quite strong impatience ( $b_2 = 0.8b_1 = 21.8047$ ) and modest curvature of the sub-utility function  $\phi$  ( $\eta = 0.1$ ).

The resulting sequence of the main endogenous variables when there is no road is set out in the upper panel of Table 1. Three generations on, in some 60 years, a young adult is over three times more productive and enjoys a level of real consumption likewise three times higher than his or her great-grandparents were in young adulthood in period 1.

Table 1: The sequences of the main variables, with and without the road

Period		1	2	3	4
No Road	$x_{1t}$	2.8177	3.6598	5.9275	9.2346
	$x_{2t}$	2.3054	2.9943	4.8495	7.5556
	$e_t^0$	0.4310	0.8664	0.8664	0.8664
	$\lambda_t^2$	1.7000	2.1457	3.8791	5.6195
Road: Variant 1	$x_{1t}$	2.7605	3.8022	6.4384	10.4149
	$x_{2t}$	2.4976	3.4401	5.8252	9.4230
	$e_t^0$	0.4907	0.9366	0.9366	0.9366
	$\lambda_t^2$	1.7000	2.3044	4.2567	6.4454
Road: Variant 2	$x_{1t}$	2.7537	3.8173	6.4631	10.4478
	$x_{2t}$	2.4914	3.4538	5.8476	9.4527
	$e_t^0$	0.4959	0.9366	0.9366	0.9366
	$\lambda_t^2$	1.7000	2.3182	4.2692	6.4661

Variant 1:  $q_1 = 0.125, q_t = 0.053 \forall t \geq 2$ . Variant 2:  $q_1 = 0.101625, q_t = 0.0451 \forall t \geq 2$ .

## 4.2 Life with the road

We need to specify how the road improves the household's environment in period 1, as described by the vector  $\mathbf{Z}_1$ . Starting with unit transport costs for goods, Bell and van Dillen (2012) estimate that these are reduced by about 5 percent of the net price received for commodities marketed. Khandker *et al.* (2009) obtain a similar estimate for rural roads in Bangladesh, once an allowance is made for greater volumes marketed. They also estimate that the farm-gate price of fertilizers declined by 5 percent. With a new road, therefore, let  $\mathbf{p}_1 = (0.95, 1.05)$ . Where schooling is concerned, Bell and van Dillen's (2012) analysis of the Orissa survey yields substantial savings in travel-time for secondary-school pupils (just over 30 minutes a day) and far fewer days of involuntary absences for all grades (about 2 instead of about 9 for primary and 14 for secondary). These estimates imply  $\tau = 0.04$  and  $\bar{e}_t = (1 - 2/180)(1 - d_t^1)/(1 + 0.04) = 0.9508(1 - d_t^1)$ .

It is not to be expected that the provision of an all-weather road will have such strong effects on morbidity, at least in the very short run; and Bell and van Dillen (2012) find none in the Orissa villages. Households did, however, respond by switching away from local healers, quacks and primary clinics to hospitals, which certainly suggests that all-weather roads are valued in this connection. To be quite conservative, therefore, let there be no improvement in  $\mathbf{d}_t \forall t$ . The findings where mortality is concerned are mixed. An analysis of individual mortality in the sample households revealed no effects; but the respondents in the village 'focus group' interviews were adamant that mortality had dropped sharply, as the acutely sick and injured could be treated in good time. According to their claims, in the group of nine such villages, the average number of such deaths had dropped from 3.25 to 0.75 annually. Even allowing for 'unavoidable' deaths, these claims are rather startling; for the crude mortality rate of about 10 per 1000 in the sample drawn from all 30 villages implies just 10 deaths annually in a typical village of 1000 souls. Since  $q_t$  is assumed to fall from 0.125 in period 1 to 0.053 in period 2 even with no road, let the provision of the road reduce  $q_1$ , not by the implied 25 percent or so, but rather by 10 percent, to 0.1125.

Turning to future periods, let the road be perfectly durable, thereby maintaining these more favourable prices of goods, as well as travel-times to, and involuntary absences from, school indefinitely. As argued in Section 3.2, however, morbidity and mortality will surely fall over the next generation even in the absence of a road. Staying on the conservative side, let the road continue to have no effect on morbidity in period 2, but let the 10 percent reduction in mortality continue to hold, so that  $q_2 = 0.0477$ . Thereafter, all these rates remain stationary. The configuration

( $q_1 = 0.1125, q_t = 0.0477 \forall t \geq 2$ ) is denoted by (mortality) Variant 1. In view of the more striking reductions reported in the survey, we also examine Variant 2, in which there is a 15 percent reduction in  $q$ : ( $q_1 = 0.101625, q_t = 0.0451 \forall t \geq 2$ ).

The next step is to compute the sequence of perfect foresight equilibria that will arise under these more favorable sequences of  $\{\mathbf{Z}_t\}_{t=1}^{\infty}$ . The values of the main variables for the first four periods are reported in the lower two panels of Table 1. It is seen that, three generations on in Variant 1, the levels of real productivity and consumption<sup>7</sup> are about 14.7 and 18.6 percent higher, respectively, than on island 1. With the lower levels of mortality in Variant 2, the corresponding figures are 15.1 and 19.0 percent, respectively.

### 4.3 The benefits generated by the road

The EV for young adults in period 1 is obtained by finding lump-sum payments such that they would attain the same level of expected utility were they confronted instead with the less favorable environment ruling on island 1. Since most will survive into old age and, in this model, there are no financial instruments beyond pooling and the social norm expressed by  $\rho$ , it is desirable to smooth the payments. For simplicity, let there be one payment in period 1,  $T_1^2$ , which each young adult will enjoy for sure, and another of equal size in period 2, conditional on the individual surviving into old age. The level of the family's (normalized) full income in period 1 is therefore augmented by the amount  $T_1^2$ , and its allocation remains subject to the social norms expressed by  $\beta$  and  $\rho$ . In keeping with the assumption that altruism disappears with the onset of old age, let surviving individuals keep the contingent payment in period 2 wholly for themselves. Under the social norms, these receipts have no effect on their children's decisions as adults in period 2, and thus introduce no further complications into the computation of the whole sequence. The task, therefore, is to find a  $T_1^2$  such that young adults attain  $E_1 U^0$  with the road in period 1, given that they correctly forecast  $\rho \mathbf{x}_2^0$  when solving problem (15) with (normalized) full income augmented by  $T_1^2$  and so enjoy purchasing power  $\mathbf{p} \cdot \rho \mathbf{x}_2^0 + T_1^2$  in old age, conditional on their surviving to enjoy it. Given Cobb-Douglas preferences, the sum  $\mathbf{p} \cdot \rho \mathbf{x}_2^0 + T_1^2$  will be spent in proportions  $a$  and  $1 - a$  on goods 1 and 2, respectively, which completes the formulation of their decision problem, and so permits the joint computation of  $T_1^2$  and the whole sequence.

---

<sup>7</sup>Form and compare the Cobb-Douglas aggregates  $(x_{1t}x_{2t})^{0.5}$ .

The payments in question for Variants 1 and 2 are reported in the column so labeled in Table 2. To put them in perspective, recall that a young adult in period 1 can produce  $5 \times 1.7 = 8.5$  units of good 1, with a farmgate price of 0.9 in the absence of the road. In Variant 1, therefore,  $T_1^2$  is 7.7 percent of the value of this output. In the still healthier environment of Variant 2, it rises to 8.3 percent thereof. Here, it should be recalled that those who survive into old age will receive the same payment once more on reaching that phase of life, and that in view of the fact that  $T_1^2$  reflects both intertemporal substitution and pure impatience, there is no reason to discount the second (contingent) payment when summing up over both periods to yield the total benefit received by each adult who is young in period 1.

Table 2: The EV and its decomposition,  $t = 1$

	$E_1U_1$	$T_1^2$	$E_1U_1(\Delta\mathbf{p})$	$T_1^2(\Delta\mathbf{p})$	$E_1U_1(\Delta\mathbf{p}^c)$	$T_1^2(\Delta\mathbf{p}^c)$
No Road	82.8544					
Road: V1	86.1470	0.5868	85.0189	0.3994 (68.1%)	83.8044	0.2044 (34.8%)
Road: V2	86.4477	0.6379	85.0189	0.3994 (62.6%)	84.0982	0.2510 (39.3%)

Later generations also benefit, not only because the road is assumed to be perfectly durable, but also because it promotes human capital formation in period 1, and so confers higher productivity on adults in all subsequent periods. In Variants 1 and 2,  $T_2^2$  is 14.7 and 15.7 percent, respectively, of the value of a young adult's output in the absence of a road ( $5 \times 2.1457 \times 0.9$ ). These benefits, and those accruing to subsequent generations, must be discounted back to period 1 at the appropriate rate; for those receiving them arrive progressively later on the scene under conditions of improving living standards. Even so, their contribution to the discounted sum of all benefits will be large: with an inter-generational discount rate of 100 percent (almost 4 percent per annum), for example, the present value of  $T_2^2$  comfortably exceeds  $T_1^2$ .

Table 3: The EV and its decomposition,  $t = 2$ 

	$E_2U$	$T_2^2$	$E_2U_2(\Delta\mathbf{p})$	$T_2^2(\Delta\mathbf{p})$	$E_2U_2(\Delta\mathbf{p}^c)$	$T_2^2(\Delta\mathbf{p}^c)$
No Road	86.0689					
Road: V1	91.7588	1.4220	88.6707	0.6309	89.3451	0.7991
				(44.4%)		(56.2%)
Road: V2	92.1203	1.5182	88.6707	0.6309	89.7038	0.8896
				(41.6%)		(58.6%)

#### 4.4 Decomposing the contributions

The EV measures the combined benefits generated by favourable changes in transport costs, the time available for schooling, morbidity and mortality. As established in Section 2.3, the first lends itself fairly readily to empirical estimation through observation of households' actual behavior, but the last poses severe problems, as do changes in  $\bar{e}$  and child morbidity when parents decide to educate their children fully. If the parametrization of the model be accepted, however, we can proceed by answering the question, how big is the contribution of the reduction in transport costs to the EV in comparison with that of the rest taken together? For given that the former can be measured independently and empirically, the model will then yield a rough, but defensible estimate of the latter.

To recap from Sections 4.1 and 4.2, the road causes the constellation

$$\mathbf{p}_t = (0.9, 1.1) \forall t, \tau = 0.08, \mathbf{d}_1 = (0.02, 0.04, 0.08), \mathbf{d}_t = (0.015, 0.03, 0.06) \forall t \geq 2, \\ q_1 = 0.125, q_t = 0.053 \forall t \geq 2, \bar{e} = 0.866$$

to become, in Variant 1,

$$\mathbf{p}_t = (0.95, 1.05) \forall t, \tau = 0.04, \mathbf{d}_1 = (0.02, 0.04, 0.08), \mathbf{d}_t = (0.015, 0.03, 0.06) \forall t \geq 2, \\ q_1 = 0.1125, q_t = 0.0477 \forall t \geq 2, \bar{e} = 0.9366.$$

The desired decomposition involves the changes in  $\mathbf{p}_t$ . Here, the problem of path de-



pendence cannot be avoided; for the EV corresponding to the change in the whole constellation is not, except by mere fluke, additively separable in the component parts. We therefore proceed as follows. Suppose, at one extreme, the road were to affect *only*  $\mathbf{p}_t$ . As before, we can calculate the value of  $T_1^2$  that corresponds to this hypothetical change in the original constellation, and then express it as a proportion of its counterpart under the complete change. The columns labelled  $E_1U_1(\Delta\mathbf{p})$  and  $T_1^2(\Delta\mathbf{p})$  in Table 2 report the corresponding levels of expected utility and the said payments. In Variant 1, the value of the reduction in transport costs by itself makes up 68.1 percent of  $T_1^2$ , falling to 62.6 percent in Variant 2.

At the other extreme, one can calculate the payment that corresponds to all the changes in the original constellation *except*  $\mathbf{p}_t$ , which is denoted by  $T_1^2(\Delta\mathbf{p}^c)$ . The residual left after subtracting this from the value of  $T_1^2$  corresponding to the complete change is then attributable to the change in  $\mathbf{p}_t$  *plus* any interaction effects between changes in transport costs and all other changes. In Variant 1, the corresponding share is 65.2 per cent, just 2.9 percentage points smaller than that when the reduction in transport costs stands alone. The share in Variant 2 is likewise lower, at 60.7 percent. In period 2, these shares fall quite sharply, ranging between 41.4 and 44.4 percent.

By way of an independent check on these findings, one can compare the above estimates with those yielded by a completely different approach. The one that comes immediately to mind involves the derivation of the so-called Value of a Statistical Life (VSL) from variation in wage rates across occupations or industries and the associated variation, if any, in fatality rates, an approach vigorously promoted by Viscusi (for a survey, see Viscusi [1993]). Pursuing this line, Simon *et al.* (1999) employ data from Indian manufacturing firms and arrive at the rather startling estimate that the VSL is 20 to 48 times larger than the present value of lifetime foregone earnings. As the authors note, this greatly exceeds the estimate of 7 to 8 obtained by Liu *et al.* (1997) for Taiwan, China in the 1980s.

Be that as it may, what is the ratio implied by the approach adopted here? Consider Variant 1 in period 1. The equivalent sum  $T_1^2(\Delta q)$ , which is defined in relation to changes in mortality alone, stems from a reduction in  $q_1$  of 0.0125 ( $= 0.1 \times 0.125$ ). Since the said sum is paid twice, the implied VSL is 19.264 ( $= 2 \times 0.1204/0.0125$ ), which is 2.5 times the value of output in old age of a surviving young adult, namely, 7.65 ( $= 5 \times 1.7 \times 0.9$ ). The implied VSL in period 2 is 82.566 ( $= 2 \times 0.2188/0.0053$ ), as against lost output in the value of 9.656 ( $= 5 \times 2.1457 \times 0.9$ ), a ratio of just over 8.5 to one. In the present framework, however,  $T_t^2(\Delta q)$  relates not to the risk that a young

adult will fail to survive into old age and so not produce any output in that phase of life, but rather that he or she will not enjoy her claim on the common pot in old age, whose value is  $\rho \cdot \mathbf{p}_{t+1} \mathbf{x}_{t+1}$ . Young adults in period 1 face the risk of losing 5.270 in period 2, which in relation to the VSL implies a ratio of 3.66 to one. Their counterparts in period 2 face the possible loss of 8.535 in period 3, which implies a ratio of 9.67 to one. All in all, these ratios for period 1 do seem to be rather on the low side, which suggests that the benefits stemming from the posited reductions in mortality may be somewhat higher than those implicitly reported in Tables 2 and 3.

## 5 Conclusions

Providing backward rural areas with all-weather roads promotes not only production and trade in what can be called the ‘commercial’ sphere of life, but also the formation of human capital and health in the ‘non-commercial’ one. The main object of this paper has been to develop a method to value their respective contributions to the total benefit generated by rural roads. For given that obtaining independent estimates of the benefits, defined as willingness to pay, in the commercial sphere of production and trade is relatively straightforward, the respective shares of the ‘commercial’ and ‘non-commercial’ spheres in the total benefits, as derived in the unified OLG-framework employed here, then yield an estimate of the willingness to pay in the non-commercial sphere that is anchored to the independent estimate of that in the commercial sphere. Based on survey evidence from a backward region of Orissa in east India and Bangladesh, as well as elements of more usual forms of calibration, the model yields a ratio of commercial to non-commercial benefits of about two-to-one in the first generation, falling to three-to-four in the second. This is broadly consistent with the valuations expressed by respondents in the Orissa survey, who ranked the latter benefits at least on a par with the former.

# Appendix

by Jochen Laps\*

This appendix describes the solution methods used to produce the results in Tables 1, 2 and 3. To that end, it is divided into two sections. The first summarizes the parameters and exogenous variables with and without the road. The second deals with the calibration of the model, the calculation of the sequences reported in Table 1 and the equivalent variation of Tables 2 and 3. The computer package used is MATLAB. The code is available upon request.

## A.1 Parameters and Variables

The road causes the household's demographic environment and its expectations concerning the latter to change as reported in Table A.1. The vectors  $\mathbf{d}_1 = (0.02, 0.04, 0.08)$  and  $\mathbf{d}_t(0.015, 0.03, 0.06) \forall t \geq 2$  are unaffected by the road.

Table A.1: Demographic Environment

Period		1	$t \geq 2$
No Road	$(q_t^2, E_t q_{t+1})$	(0.125, 0.053)	(0.053, 0.053)
Road (V1)	$(q_t^2, E_t q_{t+1})$	(0.1125, 0.0477)	(0.0477, 0.0477)
Road (V2)	$(q_t^2, E_t q_{t+1})$	(0.10625, 0.0451)	(0.0451, 0.0451)

Table A.2 summarizes all remaining parameter values, including prices, time for travelling to and from school, and the efficiency factor in the educational technology. Some of these variables change with the road, though not across scenarios.

## A.2 Algorithm

The anchoring of the system fleshed out in Section 2 is achieved by appropriate choices for the productivity parameter  $\alpha$  and the intertemporal taste parameters  $b_1$  and  $b_2$ .

---

\* University of Heidelberg

Table A.2: Parameter Values

	$\beta$	$\rho$	$\eta$	$\gamma$	$a$	$z$	$\mathbf{p}$	$\tau$
No Road							(0.9, 1.1)	0.08
Road	0.6	0.8	0.1	0.65	0.5	0.85	(0.95,1.05)	0.04

Algorithm 1 calibrates the model such that, without the road,

$$(1 + \tau)e_1^0 = (19/40)(1 - d_1^1) \text{ and } e_2^0 = \bar{e}_2 = (19/20) \cdot (1 - d_2^1)/(1 + \tau), \quad t \geq 2. \quad (\text{A.1})$$

That is to say, a young agent in period  $t$  correctly anticipates that the next generation's optimal choice involves full education in period  $t + 1$ . This requirement has to be imposed in the maximization problem of the young agent in period  $t + 1$ . If indeed  $e_{t+1}^0 = (19/20) \cdot (1 - d_{t+1}^1)/(1 + \tau)$ , and if the general environment does not deteriorate thereafter, then the second part of equation (A.1) follows immediately. As the road encourages education, it is also clear that, with the road, agents will choose full education from period  $t + 1$  onwards. Note that the maximal education level is higher with the road

---

**Algorithm 1** Calibration

---

```

1: for  $it = 1 : maxit$  do                                 $\triangleright maxit$ : prespecified # of iterations
2:   Given  $\alpha$ ,  $b_1/b_2$ , and some initial interval  $[\underline{b}_1, \bar{b}_1]$ , solve the young adult's decision problem
3:   if  $(abs(e_1^0 - e_{1,it}^0) < tol)$  then                     $\triangleright e_1^0$  given in (A.1)
4:      $\triangleright tol = 1e - 4$ : prespecified tolerance level
5:     A solution found.
6:     Go to Algorithm 2
7:   else
8:     Adjust the taste parameter  $b_1$ , using the fact that  $e^0$  is decreasing with  $b_1$ .
9:   end if
10: end for

```

---

because of fewer days of involuntary absences and a smaller  $\tau$ . Algorithm 1 searches for the taste parameter  $b_1$ . Given  $\alpha$ , the ratio  $b_1/b_2$ , and an initial guess for the interval in which we expect the  $b_1$  satisfying (A.1) to be located, Algorithm 1 solves the young adult's decision problem (15). As  $e_{1,it}^0$  is continuous and monotone in  $b_1$ , there are root-finding methods available. I use a simple version of the derivative-free regula falsi method, which combines elements of bisection and secant methods, to solve for the

root of the function  $e_1^0 - e_{1,it}^0$ . This results in

$$\alpha = 5, b_1 = 27.2266 \text{ and } b_2 = 0.8 \cdot b_1 = 21.8047.$$

Algorithm 2 generates the sequences reported in Table 1. Before doing so, special attention is paid to the second period. If, without the road,  $e_2^0$  is either smaller than, or unreasonably higher than its maximal level  $0.95(1 - d_2^1)/(1 + \tau) = 0.866$ , then one goes back to Algorithm 1 with appropriately adjusted parameter values. Here  $z$  is a promising candidate, as the efficiency factor directly affects individual productivity,  $\lambda_t$ . Recall that for all values of  $z$  larger than 0.577, there is unbounded growth of  $\lambda_t^2$  at the rate given in equation (3). Note, however, that a value for  $z$  that is too low results in a non-monotone sequence for expected utility, at least without the road. The reason is that an inefficient educational technology is compatible with a young adult choosing extensive education for his offspring only if the weight  $n$  on the altruistic term in  $E_t U_t$  is relatively high, given  $\phi(\cdot)$ . Hence, for this model specification, the taste parameters  $b_1$  and  $b_2$  must fall dramatically with a decline in  $z$  in order to satisfy equation (A.1). If  $n$  is indeed relatively high at the outset, however, its decline along the presumed demographic transition outweighs the growth in human capital, at least in period  $t = 2$ . In order to avoid such behaviour, we set  $z = 0.85$ . The parameter constellation that yields an  $e_2^0$  consistent with (A.1) triggers the calculation of the sequence.

To complete the picture, Table A.3 displays the sequences of  $E_t U_t$  for all scenarios.

Table A.3: The sequences of  $E_t U_t$ , with and without the road

Period		1	2	3	4
No Road		82.8544	86.0689	109.1654	129.8546
Road	V1	86.1470	91.7588	117.0121	139.7707
	V2	86.4477	92.1203	117.3874	140.1497

Algorithm 3 takes as inputs the sequences for  $E_t U_t$  with and without the road and solves for the equivalent variation in terms of the family's (normalized) full income. A young adult in period  $t$  enjoys the lump-sum payment  $T_t^2$  for sure, while a second payment of  $T_t^2$  in period  $t + 1$  is conditional on surviving into old age. Note that a sole payment received as a young adult results in an equivalent variation that is greater

---

**Algorithm 2** The Sequences under Perfect Foresight

---

```
1: for  $time = 1 : T$  do ▷  $T$ : # of periods considered
2:    $\alpha, b_1, b_2$ , given.
3:   if  $e_{t,it}^0 > \bar{e}_t$  then
4:     Solve the young adult's decision problem in current and future periods with
        $e_t^0 = \bar{e}_t, t \geq 2$ .
5:   else
6:     Return to Algorithm 1 using other parameter values
7:   end if
8: end for
```

---

---

**Algorithm 3** Calculating the EV

---

```
1: for  $time = 1 : T$  do ▷  $T$ : # of periods considered
2:   for  $it = 1 : maxit$  do
3:     Given  $\alpha, b_1$  and  $b_2$  and some initial guess for the transfer  $T_t^2$ , solve the young
       adult's decision problem.
4:     if  $(abs(E_t U_t^{road} - E_t U_{t,it}^{no\ road}) < tol)$  then ▷  $tol = 1e - 4$ 
5:       A solution found.
6:     else
7:       Adjust the Transfer  $T_t^2$ , using the fact that  $E_t U_t^{no\ road}$  increases with  $T_t^2$ .
8:     end if
9:   end for
10: end for
```

---

than  $2 \cdot T_t^2$ , a reflection of the desire to smooth out consumption over the life cycle. Algorithm 3 finds the transfer  $T_t^2$  that yields  $E_t U_t^0$  with the road in period  $t$  when solving the young adult's decision problem without the road but with (normalized) full income augmented by  $T_t^2$ , given a correct forecast of his purchasing power in old age,  $\mathbf{p}\rho\mathbf{x}_{t+1}^0 + T_t^2$ . As expected utility is continuous and strictly increasing in  $T_t^2$  the regula falsi method is again appropriate. The system is much simplified by the assumption that altruism disappears in old age, because the transfer received in this stage of life will not affect the individual's children's future decisions as adults. Note that the transfer in period  $t = 1$  alters the current optimal decision and hence the future environment such that the system exhibits path dependency with respect to the transfer payments. In order to find the equivalent variation for periods later periods,  $t \geq 2$ , one then has to reset the  $E_t U_t$ -sequence to its values without the road and without transfer payments. Algorithms 2 and 3 are applied to all scenarios and all decompositions of the combined benefits stemming from the road.

# References

- [1] Becker, G.S., Murphy, K.M., and R. Tamura (1990), 'Human Capital, Fertility, and Economic Growth', *Journal of Political Economy*, 98, S12-S37.
- [2] Bell, C., Bruhns, R., and Gersbach, H. (2006). 'Economic Growth, Education and AIDS in Kenya: A Long-run Analysis', Policy Research Paper No. 4025, World Bank, October.
- [3] Bell, C., and van Dillen (2012), 'How does India's Rural Roads Program Affect the Grassroots? Findings from a Survey in Upland Orissa', Policy Research Paper No. 6167, World Bank, August.
- [4] Ehrlich, I., and Lui, F.T. (1991), 'Intergenerational Trade, Longevity, and Economic Growth', *Journal of Political Economy*, 99, 1029-1059.
- [5] Khandker, S.R., Bakht, Z., and Koolwal, G. B. (2009), 'The Poverty Impact of Rural Roads: Evidence from Bangladesh', *Economic Development and Cultural Change*, 57: 685-722.
- [6] Lui, J-T., Hammitt, J.K., and Lui, J-L. (1997). 'Estimated Hedonic Wage Function and the Value of Life in a Developing Country', *Economics Letters*, 57, 353-358.
- [7] The MathWorks, Inc. <http://www.mathworks.com>.
- [8] Simon, N.B., Cropper, M.L., Alberini, A., and Arora, S. (1999). 'Valuing Mortality Reductions in India: A Study of Compensating-Wage Differentials', Policy Research Working Paper No. 2078, World Bank, March.
- [9] Viscusi, W.K. (1993). 'The Value of Risks to Life and Health', *Journal of Economic Literature*, 31, 1912-1946.
- [10] World Bank (2010), 'Project Appraisal Document', Report No. 57081-IN, Washington, DC.
- [11] W.H.O. (2007), *World Health Statistics, 2007*, Geneva. [http://www.who.int/whosis/database/life\\_tables/life\\_tables.cfm](http://www.who.int/whosis/database/life_tables/life_tables.cfm)