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Abstract

Do 'local' methods of evaluation, such as partial equilibrium analysis at market prices or estimation of shadow prices, provide reliable assessments of a large rural roads programme's social profitability? Consider a small open economy with one city and a rural hinterland, two traded goods, two non-tradables, two specific factors and mobile labour. The wage in some urban employment is regulated. Revenue is raised by a tariff or an excise on the imported good. Theory and model calibration with numerical examples establish that local methods perform rather dismally. With the equivalent variation yielded by general equilibrium analysis as benchmark, the first-order partial equilibrium method grossly underestimates a programme's net benefit. Shadow prices derived on the assumption that all economic activity takes place at the border – a wholesale neglect of space – yield absurd underestimates. Two spatially sensitive variants of shadow pricing fall well short of remedying them.

Keywords: Rural roads, cost-benefit methods, general equilibrium, small open economy

JEL Classification: H54, O18, O22, R13

1 Introduction

Rural populations without access to an all-season road are legion. According to Mikou et al. (2019), 40% or more of the rural population in most developing countries live farther than 2 km from such a road, which is the received definition of lacking access (Roberts et al., 2006). Their estimates for 24 countries in sub-Saharan Africa range from 80% and upwards. The provision of access appears in the Sustainable Development Goals (SDGs), albeit without a specific target. Since investment in all infrastructure in sub-Saharan Africa at that time was a mere 1.9% of GDP (Fay et al., 2017), this omission from the SDGs is rather telling. At all events, proposals to undertake rural roads programmes on a large scale raise the question of whether they are socially profitable.

There is an extensive literature on the effects of rural roads on rural output, incomes and poverty in various countries (Fan et al., 2000; Escobal and Ponce, 2002; Khandker et al., 2009; Warr, 2010; Aggarwal, 2018; Asher and Novosad, 2020; Takada et al., 2021; Hine et al. (2019) review the more recent empirical literature.) More directly, Jacoby (2000) uses farmland values to infer the benefits of lower transport costs in Nepal. Jacoby and Minten (2009) estimate willingness to pay for rural feeder roads in Madagascar; Stifel et al. (2016) do likewise for Ethiopia. Yet valuable as they are, these contributions do not answer the question of whether the projects or programmes studied have improved social welfare; for a project or programme may, in some measure, reduce rural poverty or generate benefits for the rural population, yet at such a cost as to be socially unprofitable.

A large programme will involve heavy investment, inducing changes in prices, output, incomes and consumption throughout the economy; and these changes will depend, in general, on how it is financed. A rigorous assessment of whether it would improve welfare therefore demands general equilibrium analysis, which is a burdensome undertaking. Whether it is defensible instead to use 'local' methods of evaluation is an open question. This paper's object is to address it.

The structure employed is a small open economy, with a single city and its rural hinterland. Rural households produce a tradable good, which is exported, and general services. Urban firms produce a second tradable (good 2), transport services and general services. The latter are not transportable, so that they must be used where they are produced. Rural workers are mobile. Although the provision of rural roads has empirically important effects on health and education, these are ignored, as are any externalities.

A salient feature of public policy in such economies is the imposition, in much of the formal urban sector, of a regulated wage that lies above its market-clearing level. In the present structure, all producers of good 2 and the public sector itself are subject to this regulation; for imposing it on these employers should not be difficult in practice. The transport sector, with its numerous and diverse operators, poses real problems for regulators, the only clear exception being the railways. The same applies to producers of general services. The wage paid to transport and urban service workers, like that ruling in the rural sector, is therefore treated as completely flexible.

There are some variations. Where fiscal policy is concerned, all public expenditures are financed by either a tariff or an excise on good 2, these taxes being administratively manageable. Spatially, the city may lie at the border, or in the interior and connected to the border crossing by a trunk route.

Extensions of the road network require not only construction, but also maintenance. (Substantial parts of existing networks are often in poor condition.) Setting a baseline programme for developing countries that balances the goal of providing access against the required marginal perpetual costs, Rozenberg and Fay (2019) choose 1% of GDP. For the purposes of the numerical analysis in Sections 6 and 7, the perpetual outlay is set slightly above 1% of *status quo* GDP. The assumed yield is a halving of the unit transport services needed to ship goods 1 and 2 between the city and its hinterland.

Two kinds of what can be termed 'local' methods of programme evaluation are treated. Both involve first-order estimates of changes in prices and their effects. The first employs the standard partial equilibrium approach, which deals, in the present case, with the market for transport services. This has evident weaknesses. Not only will the programme under consideration here induce substantial changes in all prices and incomes, but the treatment of distortionary taxation and regulation, whose influence on welfare varies with the allocation of resources, is palpably incomplete.

The second kind involves the estimation of a set of shadow prices to value all goods, factor services and incomes (Little and Mirrlees, 1968, 1974; Dasgupta, Marglin and Sen, 1972; Squire and van der Tak, 1975; Drèze and Stern, 1987; Squire, 1989). It addresses, *inter alia*, the distortions in question. Two key assumptions are, first, that the project or programme is sufficiently small, and second, that in response to any perturbation, equilibrium is restored solely through changes in output and employment in a given policy regime. Thus, the salient strength of the first kind, namely, capturing the main, direct effect on welfare of a change in transportation costs, has no place in the second. To remedy this shortcoming, some first-order estimates from the first kind are incorporated into the second and valued at shadow prices. In the numerical examples of Sections 6 and 7, both local methods fare rather badly. With a correction for changes in the rural cost of living, the partial equilibrium method grossly underestimates the programme's social profitability. A first-order estimate of the change in the tax rate exacerbates this error. Shadow prices derived on the assumption that transport costs are zero, i.e., space does not matter, yield absurd underestimates. Two variants of spatially sensitive shadow pricing fall well short of redressing them.

The paper is organised as follows. The economy-wide setting is set out in Section 2. Section 3 provides a brief account of standard procedures for estimating shadow prices, followed by a proposed hybrid method in Section 4. A rigorous procedure for a spatially differentiated economy – another neglected topic in the literature – is developed in Section 5. The model is calibrated numerically and then employed to yield exact measures of a large programme's social profitability in Section 6. The corresponding application of the local methods follows in Section 7, a discussion of their performance in Section 8. The chief conclusions are drawn together in Section 9.

2 The Economy-wide Setting

The border, the city and its hinterland are denoted by the index $k = 0, 1, 2$, respectively. Households and firms are price-takers. There are two specific fixed factors, land and capital, which are used in the production of goods 1 and 2, respectively. Transport services, good 3, are produced by urban firms using labour and good 2. They are sold to all users at the urban price. General services, good 4, are produced by means of unassisted labour and are not transportable. Endowments, tastes, technologies and world prices are such that, in equilibrium, good 1 is exported and good 2 imported. The government's sole source of revenue is either an *ad valorem* tariff, t_2, or an excise, τ_2, on good 2. The aggregate net private output of good i at location k is denoted by y_{ik}. The foregoing assumptions imply $y_{12} = y_{21} = y_{31} = 0$.

The border prices of goods 1 and 2, p_i^* $(i = 1, 2)$, are exogenous. Shipping one unit of good i from location k to k' requires $a_{i,kk'}(= a_{i,k'k})$ units of good 3. Denoting the price of good i at location k by p_{ik}, the farm-gate price of good 1 is

$$p_{11} = p_1^* - (a_{1,12} + a_{1,20})p_{32}, \tag{1}$$

where $p_{10} = p_1^*$ and, if the city lies at the border, $a_{1,20} = 0$. That of good 2 is

$$p_{21} = (1 + t_2)p_2^* + (a_{2,02} + a_{2,21})p_{32},$$

where τ_2 replaces t_2 under the excise. If the city lies in the interior, urban households and firms incur transport costs on the trunk route. Under a tariff,

$$p_{12} = p_1^* - a_{1,20}p_{32},\ p_{22} = (1 + t_2)p_2^* + a_{2,02}p_{32}. \tag{2}$$

Under an excise tax, τ_2 replaces t_2 in (2) for all *users* of good 2, but firms in sector 2 do not enjoy the subsidy provided by a tariff. They obtain the net price

$$p_{22}^+ = p_2^* + a_{2,02}p_{32},$$

their competitors who import good 2 paying p_2^* for it. (Under the tariff, $p_{22}^+ = p_{22}$.)

Endowments, tastes and technologies are also such that, in all allocations, some rural workers commute to urban jobs.[1] The fraction τ_l of each unit of labour supplied to urban firms or the public sector is lost in travelling; the fare costs $a_{l,12}p_{31}$. If commuters buy goods in the city, the fact that they do so at urban prices is ignored.

The rural wage rate, w_1, is fully flexible, as is that in sectors 3 and 4, denoted by w_4. The rate in sector 2 and public employment, $\underline{w}_2$, is regulated, where $\underline{w}_2 > w_4$. Households are therefore effectively rationed in the urban labour market. The flexibility of w_1 and w_4 brings about full employment. The market-clearing equations are set out in the appendix, followed by a brief discussion of the determination of all prices in equilibrium. The following elaboration on agents' behaviour completes the structure.

2.1 The rural economy

Rural households are identical and supply their endowments completely inelastically. The derived demand for labour in sector 1, $l_{11}(p_{11}, w_1)$, and the aggregate supply function, $y_{11}[l_{11}(p_{11}, w_1)]$, follow from profit maximisation. The price of services is

[1] The importance of commuting in India is established by Asher and Novostad (2020). Migration involves various complications; it is ruled out.

equal to its marginal (equals average) cost of production:

$$p_{41} = w_1 a_{l,41}, \tag{3}$$

where the unit input requirement of labour, $a_{l,41}$, is fixed. Labour not employed in producing goods 1 and 4 is supplied to the urban economy:

$$s_{l,12} = \bar{l}_1 - l_{11} - a_{l,41} y_{41},$$

where $\bar{l}_1$ denotes rural households' aggregate endowment of labour. It is assumed that employment at the regulated wage is less than urban households' endowment of labour, and that the latter have first claim on these plum jobs; so that rural commuters are wholly employed in the unregulated urban economy. Supplying one unit of labour involves a travelling cost of $p_{l,12} = \tau_l w_4 + a_{l,12} p_{31}$. Aggregate household income is

$$m_1 = p_{11} y_{11} + p_{41} y_{41} + (w_4 - p_{l,12}) s_{l,12} = p_{11} y_{11} + w_1(\bar{l}_1 - l_{11}). \tag{4}$$

The second equality follows from (3) and the condition that, in equilibrium, w_4 less the cost of commuting to such a job be equal to w_1:

$$(1 - \tau_l) w_4 - p_{31} a_{l,12} = w_1. \tag{5}$$

2.2 The urban economy

Urban households are also identical and supply their endowments inelastically. Firms rent capital, choosing inputs so as to maximise profits. Given constant returns to scale (CRS) and perfect competition in the production of goods 2, 3 and 4, pure profits in equilibrium are zero. With capital fully employed, the derived demand for labour in the production of good 2, $l_{22}(p_{22}, \underline{w}_2)$, follows at once, and hence the aggregate supply function, $y_{22}[(l_{22}(p_{22}, \underline{w}_2)]$.

The price of good 3 is equal to its marginal (equals average) cost of production:

$$p_{32} = p_{22}a_{23} + w_3 a_{l3}, \tag{6}$$

where the unit input requirements of labour and good 2, a_{l3} and a_{23}, are fixed. The assumption that transport services, once produced, are available everywhere implies $p_{31} = p_{32}$. The urban price of general services is

$$p_{42} = w_4 a_{l,42}.$$

Urban households' aggregate income is the sum of value added in urban production and earnings in public sector employment, less wages paid to rural commuters:

$$m_2 = p_{22}y_{22} + w_3 a_{l3} y_{32} + p_{42}y_{42} + \underline{w}_2(-z_{l1} - z_{l2}) - w_4(1 - \tau_l)s_{l,12}, \tag{7}$$

where $-z_{lk}\,(\geq 0)$ denotes the level of employment in the public sector at location k and, in equilibrium, $w_3 = w_4$.

2.3 The public sector

Public sector firms trade at market prices. Let z_{ik} denote their net output of good $i\,(= 1, 2, 3, 4, l)$ in location k, where the vector $\mathbf{z}$ also includes public goods, g. Let $\mathbf{z}^1$ denote the public sector's net supply vector when the network of rural roads is in its original condition and $\mathbf{z}^2$ that when some programme of improvements has been undertaken. The difference $\Delta\mathbf{z} \equiv \mathbf{z}^2 - \mathbf{z}^1$ involves only the inputs required to construct and maintain those improvements.

The government balances its budget, and private agents do likewise. It then follows from Walras's law that the economy's foreign account is also balanced:

$$p_1^* e_1 + p_2^* e_2 + z_f = 0, \tag{8}$$

where e_i denotes the net exports of good i $(= 1, 2)$ and z_f the public sector's endowment of foreign exchange.

2.4 Welfare

Let the arguments of the social welfare function, Ω, be rural and urban households' levels of utility, as given by the functions $v_1(\mathbf{p}_1, m_1)$ and $v_2(\mathbf{p}_2, m_2)$, and the bundle of public goods produced by the vector $\mathbf{z}^1$, $g(\mathbf{z}^1)$.

Assumption 1 $\Omega = W(v_1, v_2) + h(g)$.

Given the assumption that $\Delta\mathbf{z}$ involves only the inputs required by the programme, the latter induces no changes in g and so yields the change in welfare:

$$\Delta\Omega = \Delta W = W[v_1(\mathbf{p}_1^2, m_1^2), v_2(\mathbf{p}_2^2, m_2^2)] - W[v_1(\mathbf{p}_1^1, m_1^1), v_2(\mathbf{p}_2^1, m_2^1)]. \tag{9}$$

For the purposes of comparison with the local methods, it will be useful to express (9) in terms of money-metric utility. Let Δm_k^e be the sum such that the households at location k are indifferent between having the programme and the *status quo*, but in the latter case with income augmented by Δm_k^e such that $v_k(\mathbf{p}_k^1, m_k^1 + \Delta m_k^e) = v_k(\mathbf{p}_k^2, m_k^2)$.

Assumption 2 *The marginal social valuations placed on v_1 and v_2 are equal.*[2]

Then ΔW reduces to the (algebraic) sum of Δm_1^e and Δm_2^e: $\Delta W = \Delta m_1^e + \Delta m_2^e$ is the programme's equivalent variation (EV).

[2]Allowing them to differ will obscure the comparisons that follow. In practical applications, there may well be compelling reasons for them to differ.

2.5 Some qualitative analysis

Whether the programme $(\Delta\mathbf{a}, \Delta\mathbf{z})$ will improve welfare can be firmly established only by estimating all prices and quantities in equilibrium with the programme and comparing that allocation with the *status quo ante*, where the latter is, in principle, observable at the time of evaluation. Even so, the following first-order calculation is instructive.

Suppose the programme induces changes only in the farm-gate prices of goods 1 and 2 though its direct effect $\Delta\mathbf{a}$, all other prices and all quantities remaining unchanged. Then rural households would obtain the increase in income

$$\Delta m_1 \;=\; (a^1_{1,12} - a^2_{1,12})p^1_{32}y^1_{11} + [(\tau^1_l - \tau^2_l)w^1_4 + (a^1_{l,12} - a^2_{l,12})p^1_{32}]s^1_{l,12}. \tag{10}$$

At the hypothesised price vector

$$\mathbf{p}^2_1 = (p^*_1 - (a^2_{1,12} + a_{1,20})p^1_{32}, (1 + t^1_2)p^*_2 + (a_{2,02} + a^2_{2,21})p^1_{32}, p^1_{41}), \tag{11}$$

$m^2_1 = m^1_1 + \Delta m_1$ yields Δm^e_1. Under the said assumptions, urban households' welfare would remain unchanged and the cost of generating Δm^e_1 would be $\mathbf{p}^2 \cdot \Delta\mathbf{z}$.

Whether the resulting quantity $\Delta m^e_1 - \mathbf{p}^2 \cdot \Delta\mathbf{z}$ is close to the programme's EV depends on various factors, not all pulling in the same direction. First, there is the change in the price of transport services, any increase in which will offset, at least in part, the reduction in $\mathbf{a}$. For the latter makes the production of good 1 more profitable and so increases the derived demand for labour and hence the unregulated wage rates, thus inducing an increase in p_{32}. If the city lies in the interior, transport costs on the trunk route will also rise. Since good 4 is produced by unassisted labour, p_{41} and p_{42} will increase *pari passu* with w_1 and $w_4\,(= w_3)$, respectively, where those rates are connected by (5). Higher earnings are accompanied by higher consumer prices.

There is also the need to finance the programme, which may be fiscally infeasible under a tariff, whose base is relatively narrow. If the programme fails to induce a sufficiently strong expansion of international trade, t_2 will rise, thus reinforcing the increase in p_{32} induced by the increase in w_3. Both effects increase the farm-gate price of good 2, but urban households will enjoy the larger implicit production subsidy, with a net gain if domestic production of good 2 exceeds urban consumption thereof. There is no such compensation under an excise on good 2, whose wider base makes for a lower *status quo ante* rate and a smaller increase therein to finance any given programme. All households face a correspondingly higher consumer price.

As for the programme's direct cost, $\mathbf{p}^2 \cdot \Delta\mathbf{z}$, in practice this comprises largely wages, paid at the regulated rate. Under the foregoing assumptions, changes in the tax base and rate are ruled out, and hence any change in revenue in full equilibrium.

Taken together, the factors discussed above point rather to $\Delta m_1^e - \mathbf{p}^2 \cdot \Delta\mathbf{z}$ being an overestimate of the EV. Pulling in the opposite direction are the gains from substitution in production and consumption, which are ruled out by assumption. If such substitution possibilities are substantial, so too will be the associated gains in welfare.

To sum up, if (i) the programme $(\Delta\mathbf{a}, \Delta\mathbf{z})$ is technically quite efficient in the sense that spending $\mathbf{p}^2 \cdot \Delta\mathbf{z}$ yields a relatively large reduction in $\mathbf{a}$, so that the latter overwhelms any increase in the price of transport services, and (ii) there is sufficient substitutability in production and consumption, then the first-order estimate of the quantity $\Delta m_1^e - \mathbf{p}^2 \cdot \Delta\mathbf{z}$ will be an underestimate of the EV.

3 Shadow Prices: Standard Procedures

Although the commonly employed procedures for estimating shadow prices are well known, certain complications arise in a spatially differentiated economy, which have not received close attention. To clarify what is involved, there follows an account of how to treat space in those procedures, using the four-good structure of Section 2.

The shadow price of good i at location k, denoted by π_{ik}, is *defined* to be the increase in social welfare resulting from a unit (small) increase in the quantity thereof available to the public sector. Let public income be the numéraire, so that the shadow prices of traded goods at the border are equal to their respective border prices: $\pi_{i0} = p_i^* \ (i = 1, 2)$. The shadow price of good 3 is equal to the cost, at shadow prices, of producing it – by assumption, in the city. Suppose the city is a port; or, if it lies in the interior, ignore transport costs along the trunk route, yielding $\pi_{i2} = p_i^* \ (i = 1, 2)$. Then

$$\pi_{32} = p_2^* a_{23} + \pi_{l2} a_{l3}, \tag{12}$$

where π_{l2} is the shadow wage rate.

The shadow price of good 1 in the hinterland is net of the social cost of transporting it to the border:

$$\pi_{11} = p_1^* - \pi_{32}(a_{1,12} + a_{1,20}).$$

That of good 2 in the hinterland includes the social cost of transporting it there:

$$\pi_{21} = p_2^* + \pi_{32}(a_{2,21} + a_{2,02}).$$

The shadow price of good 4 is its marginal social cost of production:

$$\pi_{4l} = \pi_{lk} a_{l,4k}, \ k = 1, 2.$$

To obtain the shadow wage rate, make no distinction between its value at the two locations. If the public sector employs an additional worker, the standard assumption is that he or she will be drawn out of the production of good 1, and so will give up w_1 in exchange for the regulated wage. The resulting fall in the output of good 1 is the marginal product of labour: $\partial y_{11}/\partial l_{11} = w_1/p_{11}$. Hence, the social opportunity cost of labour is $[p_1^* - \pi_{32}(a_{1,12} + a_{1,20})]w_1/p_{11}$. This is not, however, equal to the shadow wage rate. For the worker enjoys an increase in income in the amount $\underline{w}_2 - w_1$, which is socially valuable; it is also spent on some bundle of goods and therefore entails a social cost. Let each unit of additional rural income be spent on the bundle (c_{11}, c_{21}, c_{41}). Then the social cost resulting from the said gain in income is

$$[(p_1^* - \pi_{32}(a_{1,12} + a_{1,20}))c_{11} + (p_2^* + \pi_{32}(a_{2,21} + a_{2,02}))c_{21} + \pi_{41}c_{41}]\,(\underline{w}_2 - w_1) \equiv \gamma_1(\underline{w}_2 - w_1),$$

where γ_1 is the consumption conversion factor (CCF). Let the social value of each unit of income accruing to a rural worker be θ_1, whose value is derived outside this procedure. The deadweight losses of distortionary taxation and the assumption that increases in public income are saved combine to yield a premium on public over private income ($\theta_1 < 1$). Combining all three elements, the shadow wage rate is

$$\pi_{l2} = [p_1^* - \pi_{32}(a_{1,12} + a_{1,20})]w_1/p_{11} + (\gamma_1 - \theta_1)(\underline{w}_2 - w_1). \quad (13)$$

Solving (12) and (13) yields π_{32} and π_{l2}, and hence π_{11}, π_{41} and π_{42}, thus completing $\boldsymbol{\pi}$. At each location, π_{ik} includes the social costs of transporting goods between the hinterland and city, albeit neglecting those along the trunk route.

4 A Hybrid: Changes in Market Prices

The foregoing procedure does not take full account of the fact that, by reducing $\mathbf{a}$, even a small project in the form of a feeder road will reduce transport costs for the villages it serves without affecting all shadow and market prices. The feeder will leave p_{32} unchanged, but the reduction in $\mathbf{a}$ will increase p_{11} and reduce p_{21} in those villages, thus measurably affecting the villagers' cost of living as well as their incomes. The following procedure seeks to remedy this omission of changes in market prices.

The EV, as assessed by the villagers, is Δm_1^e; its value in numéraire units is $\theta_1 \Delta m_1^e$. Since the project is small, any change in t_2, and hence in π_{32}, will be of second order.

Although the feeder does not affect π_{32}, it changes the shadow prices of goods 1 and 2 in the *villages served* by reducing $a_{1,12}$ and $a_{2,21}$: $\pi_{11}^2 = \pi_{11}^1 + \Delta a_{1,12}\pi_{32}$ and $\pi_{21}^2 = \pi_{21}^1 - \Delta a_{2,21}\pi_{32}$, where $\Delta a_{1,12} = a_{1,12}^2 - a_{1,12}^1$ and $\Delta a_{2,21} = a_{2,21}^2 - a_{2,21}^1$. If shadow prices diverge from market prices, the social cost of private expenditures will not, in general, be equal to their value at market prices. Spending m_1^1 generates a social profit of $m_1^1 - \boldsymbol{\pi}^1 \cdot \mathbf{x}_1^1$, which may take either sign; likewise, spending m_1^2 generates $m_1^2 - \boldsymbol{\pi}^2 \cdot \mathbf{x}_1^2$. Hence, the project's social profit, in numéraire units, is

$$\Pi_1 = \theta_1 \Delta m_1^e + (m_1^2 - m_1^1) + [\boldsymbol{\pi}^2 \cdot (\mathbf{y}_1^2 + \mathbf{z}^2 - \mathbf{x}_1^2, l_{11}^2) - \boldsymbol{\pi}^1 \cdot (\mathbf{y}_1^1 + \mathbf{z}^1 - \mathbf{x}_1^1, l_{11}^1)], \quad (14)$$

where the negative of the expression in brackets is the social cost of generating the EV and $\mathbf{x}_1, \mathbf{y}_1$ and $\mathbf{z}$ do not include good 3, since $\boldsymbol{\pi}$ includes all transport elements. There is the twist, moreover, that the project induces changes in shadow prices in the villages, which the procedure in Section 3 overlooks. Yet using (14) demands extensive forecasts of how the village economy will respond to the road. In effect, the setting is something like that of Section 2, but in microcosm.

Remark. In a first-best economy, shadow prices are equal to market prices, the project is financed by lump-sum taxes and there is no premium on public income. Hence, (14) reduces to the familiar result that the social profit is the excess of benefits, as measured by the EV, over the project's direct costs at market prices, all private income being spent: $\mathbf{p}_1^1 \cdot (\mathbf{y}_1^1 - \mathbf{x}_1^1) + w_1^1 s_{l,12}^1 = \mathbf{p}_1^2 \cdot (\mathbf{y}_1^2 - \mathbf{x}_1^2) + w_1^2 s_{l,12}^2 = 0$.

5 Shadow Prices in a Spatial Model

Fully specified systems of shadow prices, even for comparatively simple models, are rarely employed in practice, and to the author's knowledge, there are no applications with correspondingly differentiated spatial features. The model in Section 2 lends itself to a rigorous derivation of all shadow prices by location.

Consider the following decision problem: given $\mathbf{z}^1$ and $\underline{w}_2$, maximise Ω subject to the scarcity constraints (8) and conditions (17) - (26) in the appendix. As formulated in Section 2, the system is just determined, where the level of t_2 (alternatively, τ_2) is such that the government's budget constraint is satisfied. For present purposes, the associated Lagrangian, $\mathcal{L}$, must be written in a particular way, so that $\boldsymbol{\pi}$ can be derived by applying the envelope theorem. It extends the generic form in Drèze and Stern (1987) by setting out all spatial elements explicitly, with reference to the model under consideration here. Rather unwieldy in form, it is consigned to the appendix. The shadow prices are the respective changes in W resulting from marginal changes in the government's net supply vector. The envelope theorem yields

$$\pi_{ik} \equiv \frac{\partial \mathcal{L}^0}{\partial z_{ik}} = \frac{\partial W^0}{\partial z_{ik}} = \lambda_{ik}, \quad i = 1,2,3,4, \ k = 0,1,2,$$

$$\pi_{lk} \equiv \frac{\partial \mathcal{L}^0}{\partial z_{lk}} = \frac{\partial W^0}{\partial z_{lk}} = \lambda_{lk} + \mu_2 \underline{w}_2, \quad k = 1,2$$

$$\pi_f \equiv \frac{\partial \mathcal{L}^0}{\partial z_f} = \frac{\partial W^0}{\partial z_f} = \lambda_f,$$

where the superscript '0' refers to the optimum of the said decision problem and $\boldsymbol{\lambda}$ denotes the vector of the multipliers associated with the scarcity constraints. The shadow wage rate, π_{lk}, relates to the reduction in W^0 when more labour is employed in ($z_{lk} < 0$), as opposed to produced by, the public sector at location k. It should be noted that π_{lk} is not equal to the multiplier λ_{lk} associated with the scarcity constraint at location k; for the regulated wage rate is in play, and the payments $-\underline{w}_2 z_{lk}$ appear in (7), whose associated multiplier is μ_2, but not in (4), whose multiplier is μ_1. The shadow price of public income is λ_f, which is associated with (8).

At the optimum, $\mathcal{L}$ must be stationary w.r.t. all endogenous variables, whether they be chosen by the government or adjust so as to bring about equilibrium. Since $\Delta\mathbf{z}$ is small and policy is fixed, changes in prices are neglected, so that it suffices to derive the f.o.c. w.r.t. $\mathbf{e}, \mathbf{y}, \mathbf{s}$ and $\mathbf{m}$. These yield a system of 14 linear equations in the 12 multipliers $\boldsymbol{\lambda}$ plus μ_1 and μ_2 (see appendix).

The shadow prices of the traded goods at the border are proportional to their respective border prices, where the factor of proportionality is the shadow price of public income: $\pi_{i0} = \lambda_f p_i^*$ $(i = 1, 2)$. The so-called border price rule holds, but only at the border. The shadow prices of the traded goods at all other locations follow from the shadow price of transport services $\pi_{32}\,(= \lambda_{32})$. The shadow price of good 1 is equal to π_{10} minus the cost, at shadow prices, of transporting one unit from that location to the border, good 1 being exported. Thus, analogously to (1), its shadow price in the hinterland when the city lies in the interior is $\pi_{10} - \pi_{32}(a_{1,12} + a_{1,20})$. The same holds, *mutatis mutandis*, for good 2 when it is transported, at some cost, into the interior.

There remains the important point that a large programme changes **a** at the level of the whole economy and hence all shadow prices, thus compounding a complication that arises even in connection with a single feeder road. If a shadow-pricing approach is employed to evaluate a programme, then both $\boldsymbol{\pi}^1$ and $\boldsymbol{\pi}^2$ are in play.

6 Large Programmes: Numerical Examples

How well do the local methods fare when measured against the procedure of section 2? In order to answer this question, a resort to numerical examples is unavoidable. Even if all solutions were available in closed form, they would involve variables so numerous and entangled with one another as to defeat attempts to derive analytically the sizes of the associated differences in the change in welfare yielded by a given programme.

The first step is to calibrate the model of the economy, followed by an application of Section 2.4 in order to yield the benchmark values.

6.1 Calibration

A natural choice of numéraire is a traded good. Let it be good 2, so that the border price $p_{20} = p_2^* = 1$; and choose units of measure such that also $p_{10} = p_1^* = 1$.

Let the technologies for producing the tradable goods exhibit CRS and be Cobb-Douglas in form, where α_{li} denotes the elasticity of the output of good i w.r.t. labour. The value $\alpha_{l1} = 0.5$ reflects rather high population densities, correspondingly high agricultural rents and fairly strong diminishing returns to labour. Such concavity is less marked in the production of good 2. Mankiw et al. (1992) settle on shares of one-third each for labour, human and physical capital. With no human capital in the present model, adding and rounding up yields $\alpha_{l2} = 0.7$. The contribution of the fixed factor is absorbed into the TFP parameter A_i.

Households' preferences are likewise Cobb-Douglas, with b_{ik} denoting the taste parameter for good i at location k. Let urban households have relatively strong tastes for services. The aggregate final demand for good i at k is $x_{ik} = b_{ik}m_i/p_{ik}$. The indirect utility functions take the form $v_k = m_k/\kappa_k(\mathbf{p}_k)$, $k = 1, 2$, where $\kappa_k(\mathbf{p}_k) = p_{1k}^{b_{1k}} p_{2k}^{b_{2k}} p_{4k}^{b_{4k}}$ is the exact (Könus) cost of living index.

The cost of a tonne-km on the trunk route is much lower than that on the tracks in the hinterland, and agricultural commodities are relatively bulky for their weight and value. Let unit shipping requirements be twice as high on the tracks as on the trunk route, and twice as high for good 1 as for good 2: without the programme, $\boldsymbol{a}_1^1 = (0.2, 0.05), \boldsymbol{a}_2^1 = (0.1, 0.025)$. The costs of commuting are assumed to arise mainly from the trip-time: $(\tau_l^1, a_{l,12}^1) = (0.1, 0.01)$. Let the programme halve all these values. Ahmed and Nahiduzzaman (2016), for example, estimate that rural roads in Bangladesh reduce the costs of transporting goods and passengers by 35% and 65%, respectively.

The constellation of parameter values (Table 1) must satisfy two conditions: first, that good 1 be exported and good 2 imported, and second, that some rural workers

Table 1: Constellation of parameter values

Parameter	Tariff	Excise	Description
Rural			
A_1	2.9	3.2	TFP parameter, good 1
$\boldsymbol{\alpha}_1$	$(0.5, 0.5)$	$(0.5, 0.5)$	elasticity of output w.r.t. labour and land
$\mathbf{b}_1$	$(0.4, 0.4, 0.2)$	$(0.4, 0.4, 0.2)$	taste parameters
$\bar{l}_1$	1.25	2.0	labour endowment
$\boldsymbol{a}_1^1$	$(0.2, 0.05)$	$(0.2, 0.05)$	unit transport requirement, without programme
$\boldsymbol{a}_1^2$	$(0.1, 0.05)$	$(0.1, 0.05)$	transport requirement, with programme
$(\tau_l^1, a_{l,12}^1)$	$(0.1, 0.01)$	$(0.1, 0.01)$	commuting time and fare elements, without programme
$(\tau_l^2, a_{l,12}^2)$	$(0.05, 0.005)$	$(0.05, 0.005)$	commuting time and fare elements, with programme
Urban			
A_2	1.5	2.0	TFP parameter, good 2
$\boldsymbol{\alpha}_2$	$(0.7, 0.3)$	$(0.7, 0.3)$	elasticity of output w.r.t. labour and capital
$\mathbf{b}_2$	$(0.35, 0.35, 0.3)$	$(0.35, 0.35, 0.3)$	taste parameters
$\bar{l}_2$	0.75	1.3	labour endowment
$\boldsymbol{a}_2^1$	$(0.1, 0.025)$	$(0.1, 0.025)$	unit transport requirement, without programme
$\boldsymbol{a}_2^2$	$(0.05, 0.025)$	$(0.05, 0.025)$	unit transport requirement, with programme
$\mathbf{a}_3$	$(0, 0.2, 0, 1)$	$(0, 0.2, 0, 1)$	unit input requirements, sector 3
$\underline{w}_2$	1.97	1.8	regulated wage in sector 2 and public employment
Public sector			
$\mathbf{z}^1$	$(0, 0, 0, -0.05)$	$(0, 0, 0, -0.1)$	net output vector, without programme
$\mathbf{z}^2$	$(0, 0, 0, -0.07)$	$(0, 0, 0, -0.14)$	net output vector, with programme
$\mathbf{p}^*$	$(1, 1)$	$(1, 1)$	border prices of goods 1 and 2

N.B. For the port city, $a_{1,20} = a_{2,02} = 0$.

commute to urban jobs, both conditions holding with and without the programme. The narrower tax base of the tariff turns out to create real difficulties in this regard, so that it is necessary to allow some parameter values to vary with the tax. The TFP values are set higher, and the regulated wage lower, under the excise, where the value of $\underline{w}_2$ under the tariff is very close to the critical minimum for the constellation in question. Both populations are assumed to be quite rural, but the economy's total endowment of labour is considerably higher under the excise, in keeping with the higher TFP values.

The public sector, which employs only labour, is also smaller under the tariff: $-z_l^1 = 0.05$, i.e., 2.5% (= 0.05/2) of the workforce, without the programme. The programme requires additional public employment in the amount $\Delta z_l = -z_l^2 + z_l^1 = 0.02$, whose associated cost, with workers paid the regulated wage, amounts to 1.1% of the *status quo ante* GDP in both city settings. The values under the excise are $-z_l^1 = 0.10, -z_l^2 =$

-0.14 and 1.3%, respectively.

As for the structure of the *status quo ante* GDP, the parameter constellation under the tariff yields the following percentage shares of sectors 1-4 and government, respectively: for the port-city, 47.9, 14.7, 11.1, 23.6, 2.7; for the interior city, 42.4, 20.1, 10.8, 23.9, 2.8. The corresponding shares under the excise are, respectively, 43.8, 19.9, 9.1, 24.0, 3.2 and 40.3, 23.2, 9.0, 24.2, 3.3.

6.2 Exact welfare analysis

The procedure of Section 2.4 involves determining the complete allocations in the *status quo* and with the programme. It suffices to deal with those concerning welfare.

With a tariff on good 2, the values of W for the port-city setting are $W^1 = 2.354 + 1.145 = 3.499$ and $W^2 = 2.574 + 1.181 = 3.755$. Rural households are a good deal better off with the programme; urban households also gain somewhat. The EV for residents of location k is Δm_k^e such that $(m_k^1 + \Delta m_k^e)/\kappa_k(\mathbf{p}_k^1) = v_k^2\,(k = 1, 2)$. This condition yields $\Delta m_1^e = 0.216$ and $\Delta m_2^e = 0.041$. The programme's EV is their sum, 0.257 (see Table 2), which is 7.1% of the *status quo* GDP.

When the city lies in the interior, the changes in certain variables are large. The increase of 21% in the farm-gate price is accompanied by an increase of 19% in exports. The resulting increase in the tax base keeps the increase in t_2 modest: it rises from 13.8% to 16.2%. As for the EV, $W^1 = 2.206 + 1.217 = 3.423$ and $W^2 = 2.389 + 1.267 = 3.656$. Comparing these with their counterparts for the port city, transport costs on the trunk route inflict an aggregate loss of 2.1% and 2.6%, respectively. Proceeding as before, $\Delta m_1^e = 0.177$, $\Delta m_2^e = 0.056$ and the EV is 0.223. Urban households do better, both relatively and absolutely, than their counterparts in the port-city setting.

The results for the excise tax are as follows. In the port-city setting, τ_2 increases from 9.6% to 12.1%; $W^1 = 3.484 + 2.030 = 5.514$ and $W^2 = 3.776 + 2.047 = 5.823$.

Then, $\Delta m_1^e = 0.282$ and $\Delta m_2^e = 0.018$, yielding EV $= 0.300$, or 5.4% of the *status quo* GDP. When the city lies in the interior, τ_2 increases from 10.3% to 13.0%; $W^1 = 3.339 + 2.113 = 5.452$ and $W^2 = 3.606 + 2.132 = 5.738$. Then, $\Delta m_1^e = 0.250$ and $\Delta m_2^e = 0.020$, yielding EV $= 0.270$, or 5.0% of the *status quo* GDP. Transport costs on the trunk route inflict an aggregate loss of 5.3% and 5.0% without and with the programme, respectively.

Results were also derived for a transport technology that is much more intensive in good 2 and less so in labour, with a small increase in A_2 in compensation: $a_{23} = 0.6, a_{l3} = 0.7$. All the chief qualitative findings still hold (see Table 4 in the appendix).

There is an improvement in urban welfare in all variations: 15% to 25% of the aggregate EV accrues to urban households under the tariff, and 6.0% to 7.4% under the excise. Urban households benefit from the additional public sector jobs paying the regulated wage. Under the tariff, they also benefit from the larger subsidy provided by the increase in t_2 ($y_{22} > x_{22}$). There is no such subsidy under the excise, but the programme induces an increase in the price of transport services, which matters when the city lies in the interior; for then producers of good 2 enjoy a higher net price. Rural households enjoy more income from sector 1; but the level of their urban employment contracts so strongly that they earn less from commuting, despite lower unit commuting costs and a higher unregulated wage in urban employment.

7 'Local' Methods: Numerical Examples

The *status quo* allocation of resources is, in principle, observable at the time of evaluation. This allocation therefore provides the basis for the following analysis.

7.1 Partial equilibrium: market prices

The provision of rural roads directly reduces the cost of shipping goods and a commuter's round trip. The first-order procedure in Section 2.5 involves the corresponding changes in the village prices of goods 1 and 2 and commuting, but not in the prices of transport services and other goods, nor in wages.

Eqn. (10) yields the estimate of the benefits. Under a tariff in the port-city setting, $\Delta m_1 = 0.1 \cdot 3.850 + 0.073 \cdot 0.104 = 0.393$. Rural income, m_1^1, is observed to be 2.321, so that the first-order estimate of m_1^2 is 2.714. Subtracting from 0.393 the direct cost of the programme, namely, $-\underline{w}_2(z_l^2 - z_l^1) = 0.0394$, the resulting net benefit is 0.354, which is 38% larger than the EV. The corresponding estimate when the city lies in the interior is $0.369 - 0.0394 = 0.330$, which is 42% greater than the true value, 0.233. The overestimates under an excise on good 2 are larger still (see Table 2).

The foregoing calculations neglect the effects of lower unit transport costs on rural consumer prices. The price vector given by (11) yields a Laspeyres index of 1.065 in the port-city setting. Deflating m_1^2 accordingly and subtracting m_1^1 yields $\Delta m_1^e = 0.227$ and a net benefit of 0.188. The corresponding figure when the city lies in the interior is 0.157. Egregious overestimates become almost equally egregious underestimates.

Relaxing the foregoing restriction on changes in prices to the direct ones of improving the network, suppose the tax rate rises in the same proportion as the outlays on the programme relative to the *status quo ante* level of public expenditures, that is, in the proportion $\Delta z_l/(z_{l1} + z_{l2}) = 0.02/0.05$. The resulting changes in $\mathbf{p}_k$ are readily calculated. In the port-city setting, the Laspeyres index is 1.082, $\Delta m_1^e = 0.185$ and the net benefit is just 0.139. When the city lies in the interior, their values are 1.085, 0.169 and 0.130, respectively. The foregoing underestimates are exacerbated.

Table 2: Social benefits and costs: methods, city location and taxes

City location	Port			Interior		
	benefits [a]		costs	benefits [a]		costs
Tariff on good 2						
General equilibrium (EV) [b]	0.257	0.257	0	0.233	0.233	0
Market prices	0.393	0.227	0.039	0.369	0.196	0.039
Shadow prices: cookbook	0.221	0.089	0.041	0.201	0.063	0.043
Shadow prices: standard	0.320	0.187	0.026	0.304	0.166	0.025
Shadow prices: spatial	0.374	0.231	0.035	0.325	0.191	0.033
Excise on good 2						
General equilibrium (EV) [a]	0.300	0.300	0	0.270	0.270	0
Market prices	0.503	0.295	0.068	0.474	0.264	0.068
Shadow prices: cookbook	0.292	0.126	0.072	0.266	0.098	0.076
Shadow prices: standard	0.404	0.238	0.049	0.380	0.212	0.047
Shadow prices: spatial	0.517	0.320	0.066	0.502	0.296	0.065

Author's calculations.

[a] Benefits deflated by the first-order (Laspeyres) index are given in the second column.

[b] The general equilibrium estimates are inherently net of all costs. The direct costs of $\Delta \mathbf{z}$ at market prices are reported in the corresponding row. Since the numéraire for shadow prices is public income, these rows must be multiplied by $1/\theta$ or $1/\mu_1$, as appropriate, for comparisons with those for the EV and market prices.

7.2 Shadow prices: standard procedures

The method in Section 3 requires that the value of the parameter θ_1 be supplied from elsewhere. A common, rule-of-thumb value is 0.8: equivalently, a premium of 25% $(= ((1/0.8) - 1) \cdot 100)$ on public income.

In actual practice, there is almost invariably a resort to the implicit assumption that all activities take place at some border location: that is, set all unit transport requirements equal to zero when employing (12) and (13). The border-price rule yields $\pi_{1k} = \pi_{2k} = 1$. Solving (12) and (13) in the port-city setting yields $\pi_{32} = 2.230, \pi_l = 2.030$; when the city lies inland, $\pi_{32} = 2.366, \pi_l = 2.166$ (see Table 3). This particular shortcut is termed the 'cookbook' method.

Turning to the programme itself, the change in the public sector's net supply vector is just the employment of the workers needed to construct and maintain the new rural roads, namely, $-(z_l^2 - z_l^1)$. The resulting change in the vector of net outputs, chiefly of good 1, occurs in the private sector.

Suppose there were changes in neither $\mathbf{y}_1$ nor p_{32}, as in the first-order procedure of Sections 2.5 and 7.1. Suppose further that the same holds for $\boldsymbol{\pi}$, and that no correction were made for changes in the cost of living. Then (14) would specialise to

$$\Pi_1 = (1 + \theta_1 - \gamma_1)(\mathbf{p}_1^2 - \mathbf{p}_1^1) \cdot \mathbf{y}_1^1 + \boldsymbol{\pi} \cdot \Delta\mathbf{z} = (1 + \theta_1 - \gamma_1)\Delta m_1 + \boldsymbol{\pi} \cdot \Delta\mathbf{z}. \qquad (15)$$

Applying the cookbook rule in the port-city setting yields $\Pi_1 = (1+0.8-1.236) \cdot 0.393 - 2.030 \cdot 0.02 = 0.181$. The corresponding estimate when the city lies in the interior is $(1 + 0.8 - 1.255) \cdot 0.369 - 2.166 \cdot 0.02 = 0.158$. In order to compare these estimates of the programme's EV, whose numéraire is effectively (real) private income, the said estimates must be multiplied by $1/\theta_1$ (= 1.25), yielding 0.226 and 0.198, respectively. Under the excise, the net benefits are 0.220 and 0.190, respectively; after normalisation for comparison, 0.275 and 0.238, respectively. All are quite substantial underestimates, with γ_1 lying in the interval $(1.22, 1.26)$.

A further step is needed, namely, deflation of the private monetary benefits. The procedures for estimating shadow prices effectively treat income as real income; so that m_1^2 should be deflated to yield the first-order estimate of Δm_1^e and then multiplied by θ_1 to yield units of the numéraire, as above. Actual expenditures on goods, however, are made at market prices, and any change in the bundle consumed must be valued at shadow prices. Thus, (14) specialises to

$$\Pi_1 = \theta_1 \Delta m_1^e + (1 - \gamma_1)\Delta m_1 + \boldsymbol{\pi} \cdot \Delta \mathbf{z}. \tag{16}$$

Since $\Delta m_1^e < \Delta m_1$, (16) yields an estimate of social profit smaller than that yielded by (15). Indeed, the estimates for all four location-tax variations are barely positive.

Using the cookbook method of deriving shadow prices for a spatially differentiated economy is evidently unsatisfactory. The method in Section 3 introduces the transportation elements of **a**. Under the tariff on good 2, this yields $\pi_{32} = 1.518, \pi_l = 1.318$ and $\pi_{32} = 1.472, \pi_l = 1.272$ in the port-city and interior-city settings, respectively. The shadow prices of tradable goods at a particular location are then obtained from the unit shadow costs of shipping them there (see Table 3). The programme's social profits in the city's two locations are $(1 + 0.8 - 0.986) \cdot 0.393 - 1.318 \cdot 0.02 = 0.294$ and $(1 + 0.8 - 0.976) \cdot 0.369 - 1.272 \cdot 0.02 = 0.279$, respectively. Normalised by $1/\theta_1$, both are much *larger* than the respective values of the EV. The corresponding net benefits under the excise on good 2 are even more adrift, at 0.342 and 0.333, respectively.

The second step is to employ (16). Under the tariff, the net benefits are 0.161 and 0.141 in the port-city and interior locations, respectively, that is, 0.201 and 0.176, respectively, after normalisation. These are *underestimates* of the corresponding EV's to the tune of 22% and 24%, respectively. Adjusting the tax rate, as in Section 7.1, lowers them further, to 38% and 36%, respectively. The proportional errors under the excise are virtually the same.

7.3 Spatially differentiated shadow prices

In the procedure of Section 5, all shadow prices, including that of public income, are mutually and simultaneously determined. Normalising $\partial W/\partial v_k$ to unity, $\partial W/\partial m_k = 1/\kappa_k$ and the f.o.c. w.r.t. m_k (see the appendix) specialises to

$$\mu_k = \frac{1}{\kappa_k} - \left(\pi_{1k}\frac{\partial x_{1k}}{\partial m_k} + \pi_{2k}\frac{\partial x_{2k}}{\partial m_k} + \pi_{4k}\frac{\partial x_{4k}}{\partial m_k}\right), \quad k = 1, 2.$$

A (small) unit increase in m_k yields a gross increase in W of $1/\kappa_k$, associated with which is the social cost of the resulting additional consumption. After the normalisation $\lambda_f = 1$, the multiplier μ_k replaces θ_k. The values of μ_1 closely straddle 0.8 under the tariff, at 0.865 and 0.776 in the port-city and interior locations, respectively. In contrast, those under the excise are almost 1, at 0.950 and 0.976, respectively.

Comparing the three shadow price vectors based on the *status quo* allocations, the cookbook method yields very crude estimates, whose pattern departs sharply from those yielded by the other two. The wholesale absence of spatial differentiation emerges as especially jarring. The method of Section 3 partly remedies this shortcoming. The shadow prices of goods 1, 2 and 3 are essentially identical to their spatially differentiated counterparts, but – importantly – the respective shadow wage rates, and hence the shadow price of good 4 in the hinterland, differ substantially.

Applying (15) with the spatially differentiated $\boldsymbol{\pi}$, the social profits under the tariff in the two locations are 0.339 and 0.292, respectively, both wild overestimates, even before normalisation by $1/\mu_1$. The values under the excise are 0.435 and 0.437, respectively, which are even farther removed from the corresponding values of the EV.

The second step, using (16), transforms these gross overestimates of social profitability into substantial underestimates. Under the tariff, the social profits in the port- and interior-city settings are 0.196 and 0.158, respectively. The values under the excise are 0.254 and 0.231, respectively. After normalisation by $1/\mu_1$, the corresponding errors

Table 3: Shadow prices by city location and taxation: three methods

	π_{11}	π_{12}	π_{21}	π_{22}	π_{3k}	π_{41}	π_{42}	π_{l1}	π_{l2}	μ_1	μ_2
Tariff											
1. Spatial											
Port	0.697	1.0	1.152	1.0	1.516	1.169	1.316	1.399	1.731	0.865	0.627
Interior	0.632	0.926	1.184	1.037	1.471	1.122	1.263	1.318	1.650	0.776	0.537
2. Standard										θ_1	
Port	0.696	1.0	1.152	1.0	1.518	1.318	1.318	1.318	1.318	0.8	
Interior	0.632	0.926	1.184	1.037	1.472	1.272	1.272	1.272	1.272	0.8	
3. Cookbook										θ_1	
Port	1.0	1.0	1.0	1.0	2.230	2.030	2.030	2.030	2.030	0.8	
Interior	1.0	1.0	1.0	1.0	2.366	2.166	2.166	2.166	2.166	0.8	
Excise											
1. Spatial											
Port	0.718	1.0	1.141	1.0	1.409	1.074	1.209	1.368	1.643	0.950	0.728
Interior	0.660	0.932	1.170	1.034	1.360	1.025	1.154	1.364	1.637	0.976	0.741
2. Standard										θ_1	
Port	0.717	1.0	1.142	1.0	1.416	1.216	1.216	1.216	1.216	0.8	
Interior	0.656	0.931	1.184	1.034	1.374	1.174	1.174	1.174	1.174	0.8	
3. Cookbook										θ_1	
Port	1.0	1.0	1.0	1.0	2.002	1.802	1.802	1.802	1.802	0.8	
Interior	1.0	1.0	1.0	1.0	2.096	1.896	1.896	1.896	1.896	0.8	

Author's calculations. Public income is the numéraire: $\pi_f = 1$. Border prices: $p_1^* = p_2^* = 1$.

range between 11% and 16% of the EV. After the third step of adjusting the tax rate, as in Section 7.1, they range from 24% to 28%.

8 Discussion

That the partial equilibrium approach performs rather dismally is no great surprise, for it leaves so much out of account, exhibiting serious drawbacks even at the level of the individual feeder road. The failure of the evaluations based on shadow prices, which address many issues neglected in the former approach, to do much better is cause for reflection, especially since shadow prices are supposed to enable the decentralisation of investment decisions in the public sector.

In general equilibrium, the tax rate normally rises in order to finance the programme, and thus increases the user price of good 2. The price of transport services also increases; for although the physical improvements in the road network are labour-saving, they promote output and trade, and hence put upward pressure on the unregulated wage rates. These changes partly offset the programme's direct, favourable effects on the rural sector's terms of trade. Another source of error is the failure to incorporate the change in rural income that results from the reallocation of labour in the economy as a whole. Under the assumption that the aggregate offer of jobs at the regulated wage is always less than urban households' endowment of labour, the burden of adjustment falls on rural households. In the numerical examples, the programme reduces the derived demand for labour in transportation so strongly that rural households' net earnings from urban employment fall. In the calculations of Section 7.1, the assumption that the number of trips stays unchanged is quite false. The wholesale neglect of changes in urban incomes and prices is a potentially much graver failing. In the numerical examples, a substantial fraction of the aggregate EV accrues to urban households under the tariff, and a non-negligible one under the excise.

A salient feature of the methods of deriving shadow prices is the assumption that, in response to a small change in the public sector's net supply vector, equilibrium in the system as a whole is re-established solely through changes in quantities. Thus derived, as exemplified in Sections 7.2 and 7.3, shadow prices capture the ensuing, fixed-price general equilibrium effects. The assumption is surely defensible when the project is an industrial one and the policy regime (tax rates and regulations) is fixed, with international trade setting the border prices of traded goods. The assumption is arguably defensible also for projects that aim to improve agricultural productivity directly, at least those on a small scale.

A rural roads programme, in contrast, induces direct changes, not in some other components of public output, but in rural prices. These induce changes directly in rural welfare, as well as in private production and consumption. In the first-order approach, partial equilibrium analysis supplies the estimate of the changes in rural income, any error in which intrudes into the estimate of social profitability at shadow prices. Some general equilibrium effects are captured by the introduction of the rural consumption conversion factor and valuing the programme's direct costs at shadow prices, but it is implausible that these closely encompass, *inter alia*, changes in urban welfare. The rigorous, but much more demanding procedure of Section 5 is clearly superior to the intuitive, shortcut approach of Section 3. Yet the end result is essentially the same as that yielded by the partial equilibrium approach, namely, egregious overestimates of social profits without first-order corrections for changes in the rural cost of living and tax rates, and very large underestimates with them.

9 Conclusions

Both theory and the numerical examples presented in this paper point to an unavoidable need for general equilibrium analysis if the evaluation of large rural road programmes is to yield reliable results. Partial equilibrium analysis, at market prices, of improvements in the network neglects much else that changes, as well the effects of distortionary taxation and regulation. If the scope for substitution in production and consumption is substantial, the resulting estimates of social profitability will err heavily on the low side. An alternative 'local' method is to estimate the shadow prices of all goods, factor services and incomes, taking into account the economy's spatial features. Such prices capture much of what the former method neglects, albeit under the assumption that adjustments in equilibrium arise only through changes in output and employment. First-order corrections to deal with changes in the cost of living and tax rates yield large underestimates of the programme's equivalent variation. More complicated corrections demand, in effect, a resort to a large part of the fully specified general equilibrium model that yields exact results. These findings will not be warmly welcomed by most practitioners.

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Appendix

Market-clearing conditions

Let $s_{i,kk'}$ denote the quantity of good i $(= 1, 2)$ shipped from location k to location k'. Given any $\mathbf{z}$, the market-clearing equations for each tradable good at location k are

$$y_{11}(p_{11}, w_1) + z_{11} = x_{11}(\mathbf{p}_1, m_1) + s_{1,12}, \tag{17}$$

$$s_{1,12} + z_{12} = x_{12}(\mathbf{p}_2, m_2) + s_{1,20}, \tag{18}$$

$$s_{1,20} + z_{10} = e_1, \tag{19}$$

$$s_{2,21} + z_{21} = x_{21}(\mathbf{p}_1, m_1), \tag{20}$$

$$y_{22}(p_{22}, \underline{w}_2) + s_{2,02} + z_{22} = x_{22}(\mathbf{p}_2, m_2) + a_{23}y_{32} + s_{2,21}, \tag{21}$$

$$z_{20} = s_{2,02} + e_2. \tag{22}$$

Transport services, once produced, are assumed to be available, at no additional cost, at any other location: $p_{31} = p_{32}$. Hence,

$$y_{32} + z_{31} + z_{32} = a_{1,12}s_{1,12} + a_{l,12}s_{l,12} + a_{2,21}s_{2,21} + a_{1,20}s_{1,20} + a_{2,02}s_{2,02}. \tag{23}$$

Services are regional goods, produced and consumed at the same location:

$$y_{4k} + z_{4k} = x_{4k}(\mathbf{p}_k, m_k),\ k = 1, 2. \tag{24}$$

The labour market clears at both locations:

$$\bar{l}_1 + z_{l1} = l_{11}(p_{11}, w_1) + a_{l,41}y_{41} + s_{l,12}, \tag{25}$$

where $s_{l,12}$ denotes the number of rural-urban commuters, and

$$\bar{l}_2 + (1-\tau_l)s_{l,12} + z_{l2} = l_{22}(p_{22}, \underline{w}_2) + a_{l3}y_{32} + a_{l,42}y_{42}, \tag{26}$$

It is seen from (1), (2) and (6) that for any given (w_1, w_4, t_2), the prices of all goods are determined, $\underline{w}_2$ and $\mathbf{p}^*$ being fixed; $l_{22}(p_{22}, \underline{w}_2)$ and $y_{22}(l_{22})$ then follow. For any w_1, the levels of $y_{11}, l_{11}, s_{l,12}$ and m_1 can be determined, and hence y_{32} from (26) and then m_2 from (7), with $\mathbf{x}_k(\mathbf{p}_k, m_k)$, $k = 1, 2$, following. The system is not, of course, thus decomposable; for w_1, w_4 and t_2 (alternatively, τ_2) are mutually and simultaneously determined with the price vectors $\mathbf{p}_1$ and $\mathbf{p}_2$, given the exogenous prices $\mathbf{p}^*$ and $\underline{w}_2$.

Suppose there exists a unique positive vector $(\mathbf{p}_1', \mathbf{p}_2', w_1', w_4', t_2')$ satisfying the above conditions and denote by $(\mathbf{y}', \mathbf{x}', \mathbf{e}', \boldsymbol{\ell}', \mathbf{m}', \mathbf{s}')$ the associated equilibrium allocation.

Spatially differentiated shadow prices

The Lagrangian encompasses the scarcity conditions (17) - (26) and the income equations (4) and (7).

$$\begin{aligned}
\mathcal{L} &= W(v_1, v_2) + \lambda_{11}[y_{11} + z_{11} - x_{11}(\mathbf{p}_1, m_1) - s_{1,12}] \\
&+ \lambda_{12}[s_{1,12} + z_{12} - x_{12}(\mathbf{p}_2, m_2) - s_{1,20}] + \lambda_{10}[s_{1,20} + z_{10} - e_1] \\
&+ \lambda_{21}[s_{2,21} + z_{21} - x_{21}(\mathbf{p}_1, m_1)] + \lambda_{22}[y_{22} + s_{2,02} + z_{22} - x_{22}(\mathbf{p}_2, m_2) - a_{23}y_{32} - s_{2,21}] \\
&+ \lambda_{20}[z_{20} - s_{2,02} - e_2] + \lambda_{41}[y_{41} + z_{41} - x_{41}(\mathbf{p}_1, m_1)] + \lambda_{42}[y_{42} + z_{42} - x_{42}(\mathbf{p}_2, m_2)] \\
&+ \lambda_3[y_{32} + z_{31} + z_{32} - a_{1,12}s_{1,12} - a_{l,12}s_{l,12} - a_{2,21}s_{2,21} - a_{1,20}s_{1,20} - a_{2,02}s_{2,02}] \\
&+ \lambda_{l1}\left[\bar{l}_1 + z_{l1} - l_{11} - a_{l,41}y_{41} - s_{l,12})\right] \\
&+ \lambda_{l2}\left[\bar{l}_2 + (1-\tau_l)s_{l,12} + z_{l2} - l_{22} - a_{l3}y_{32} - a_{l,42}y_{42}\right] + \lambda_f(z_f + p_1^* e_1 + p_2^* e_2) \\
&+ \mu_1\left[m_1 - p_{11}y_{11} - p_{41}y_{41} - [(1-\tau_l)w_4 - a_{l,12}p_{31}]s_{l,12}\right] \\
&+ \mu_2\left[m_2 + \underline{w}_2(z_{l1} + z_{l2}) - p_{22}y_{22} - w_4 a_{l3}y_{32} - p_{42}y_{42} + w_4(1-\tau_l)s_{l,12}\right].
\end{aligned}$$

where the terms involving the multipliers μ_k arise from (4) and (7).

Given $\mathbf{z}$, $(w_1', w_4', t_2', \mathbf{y}', \mathbf{x}', \mathbf{e}', \boldsymbol{\ell}', \mathbf{m}', \mathbf{s}')$ solves the optimisation problem. Under the model's assumptions, all outputs and incomes are always positive, and there are no restrictions on the signs of the other endogenous variables. Hence, the f.o.c. hold as strict equalities. Given all prices, the f.o.c. w.r.t. $\mathbf{e}, \mathbf{y}, \mathbf{s}$ and $\mathbf{m}$ are

$$\frac{\partial \mathcal{L}}{\partial e_i} = -\lambda_{i0} + \lambda_f p_i^* = 0, \quad i = 1, 2,$$

$$\frac{\partial \mathcal{L}}{\partial y_{ik}} = \lambda_{ik} - \lambda_{lk} \cdot \frac{\partial l_{ik}}{\partial y_{ik}} - \mu_k p_{ik} = \lambda_{ik} - (\lambda_{lk} + \mu_k w_i) p_{ik}/w_i = 0, \quad i = k = 1, 2,$$

$$\frac{\partial \mathcal{L}}{\partial y_{32}} = \lambda_3 - \lambda_{22} a_{23} - a_{l3}(\lambda_{l2} + \mu_2 w_4) = 0,$$

$$\frac{\partial \mathcal{L}}{\partial y_{4k}} = \lambda_{4k} - \lambda_{lk} a_{l,4k} - \mu_k p_{4k} = 0, \quad k = 1, 2,$$

$$\frac{\partial \mathcal{L}}{\partial s_{i,kk'}} = \lambda_{ik'} - \lambda_{ik} - \lambda_3 a_{i,kk'} = 0, \quad i = 1, 2, \ (k, k') = (1, 2), (2, 0),$$

$$\frac{\partial \mathcal{L}}{\partial s_{l,12}} = -\lambda_3 a_{l,12} - \lambda_{l1} + (1 - \tau_l)\lambda_{l2} - \mu_1[(1 - \tau_l) w_4 - a_{l,12} p_{31}] + \mu_2 (1 - \tau_l) w_4 = 0,$$

$$\frac{\partial \mathcal{L}}{\partial m_k} = \frac{\partial W}{\partial v_k} \cdot \frac{\partial v_k}{\partial m_k} - \lambda_{1k} \frac{\partial x_{1k}}{\partial m_k} - \lambda_{2k} \frac{\partial x_{2k}}{\partial m_k} - \lambda_{4k} \frac{\partial x_{4k}}{\partial m_k} + \mu_k = 0, \quad k = 1, 2,$$

where all variables take their values in equilibrium. If of full rank, this linear system in the variables $\boldsymbol{\lambda}$, μ_1 and μ_2 has a unique solution.

Table 4: Social benefits and costs (variant): methods, city location and taxes

City location	Port			Interior		
	benefits [a]		costs	benefits [a]		costs
Tariff on good 2						
General equilibrium (EV) [b]	0.260	0.260	0	0.246	0.246	0
Market prices	0.406	0.236	0.039	0.390	0.213	0.039
Shadow prices: cookbook	0.222	0.086	0.041	0.207	0.066	0.043
Shadow prices: standard	0.327	0.190	0.026	0.311	0.170	0.025
Shadow prices: spatial	0.354	0.206	0.035	0.343	0.188	0.034
Excise on good 2						
General equilibrium (EV) [b]	0.303	0.303	0	0.276	0.276	0
Market prices	0.523	0.306	0.068	0.501	0.274	0.068
Shadow prices: cookbook	0.293	0.120	0.073	0.268	0.086	0.077
Shadow prices: standard	0.416	0.242	0.048	0.394	0.213	0.047
Shadow prices: spatial	0.551	0.340	0.066	0.544	0.317	0.066

Author's calculations.

[a] Benefits deflated by the first-order (Laspeyres) index are given in the second column.

[b] The general equilibrium estimates are inherently net of all costs. The direct costs of $\Delta \mathbf{z}$ at market prices are reported in the corresponding row. Since the numéraire for shadow prices is public income, these rows must be multiplied by $1/\theta$ or $1/\mu_1$, as appropriate, for comparisons with those for the EV and market prices.