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Evaluating rural roads programmes

A general equilibrium analysis

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Abstract: The structure employed is a small open economy, with one city and a rural hinterland, two traded goods, a transport sector, two specific factors, and mobile labour. A socially profitable programme will promote not only internal, but also external trade. Theory and numerical examples indicate that aggregate social profitability and its distribution between town and country are rather insensitive to the city's location and whether: (i) it is financed by a tariff or an excise on the importable; (ii) the transportation wage is regulated; and (iii), when agents are risk neutral, the economy's barter terms of trade fluctuate stochastically.

Key words: rural roads, general equilibrium, social profitability, small open economy

JEL classification: H54, O18, O22, R13

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1 Introduction

The general aim of a rural roads programme is to draw the rural population into the economic mainstream. In poor areas of the world, there is much to be done. In 2006, only 33.9 per cent of the rural population of sub-Saharan Africa is estimated to have lived within two kilometres of an all-season road (Transport & ICT 2016: 3), the commonly accepted definition of 'access' to that network. The estimates for Latin America and South Asia are 59.4 and 57.3 per cent, respectively. A refined method developed by Mikou et al. (2019) and applied to more recent data yields no estimate exceeding 51 per cent for the countries of sub-Saharan Africa, and estimates of below 20 per cent for 24 of them. Yet that region's investment in *all* infrastructure is a mere 1.9 per cent of GDP, which compares unfavourably with 5.0 per cent for the South Asian subcontinent (Fay et al. 2017).

Gaining access to the all-season network should improve villagers' producer terms of trade, reduce their costs of commuting to jobs, improve attendance by teachers and pupils alike, and reduce the travel time to a clinic or hospital. In these various ways, the villagers are drawn into the mainstream, and there is an extensive literature on the effects of rural roads on rural output, incomes, and poverty.[1] Yet, a successful attempt to draw into the mainstream most or all of the legions of people now outside it would surely change the mainstream itself. Mediated by changes in prices, a comprehensive roads programme would demand heavy investment and result in changes in output, incomes, and consumption throughout the economy, accompanied by the fiscal measures needed to finance it. Nor does the mainstream end at the border. Such a programme will promote trade not only domestically, but also with the rest of the world. The latter is not an end in itself, but it has potentially important consequences. A rigorous assessment of whether such a programme would improve social welfare therefore demands a general equilibrium analysis.

Formidable complications are involved, so that some strong simplifications are unavoidable. There is a single city and a rural hinterland. In one spatial variant, the city lies at the border; it is called a port-city, even if the border is not an oceanic littoral. In the second, it lies in the interior and is connected to the border by a trunk route. The economy is small, in the sense that the border prices of traded goods are fixed. There are two such goods. Good 1 is produced in the hinterland, consumed domestically, and exported; good 2 is produced in the city and imported. Good 3 comprises transportation and storage services. It is produced in the city, is not internationally tradable, and is domestically fully mobile. Rural workers reside in the hinterland, but they can commute to urban jobs.[2] Although the provision of rural roads has empirically important effects on health and education, these are ignored.

Governments of poor countries rely heavily on taxes on international trade. In the main variant considered here, all public expenditures—including those on the programme—are financed by a tariff on good 2. A balanced-budget regime therefore involves an endogenous tariff rate. Any extension of the network will require not only construction, but also its maintenance in perpetuity. Indeed, substantial parts of existing networks are often in a poor state. For the purposes of the numerical analysis in Section 4, the perpetual outlay is set between about 0.8 and 1 per cent of GDP. The assumed, baseline yield is a halving of the unit transport services needed to ship goods 1 and 2 between the city and its hinterland, where

[1] See, for example, Fan et al. (2000), Jacoby (2000), Escobal and Ponce (2002), Jacoby and Minten (2009), Khandker et al. (2009), Warr (2010), Stifel et al. (2016), Aggarwal (2018), and Takada et al. (2021). Hine et al. (2019) review the recent empirical literature.

[2] Asher and Novostad (2020) use a regression-discontinuity approach on a sample of some 11,400 Indian villages. They conclude that the Pradhan Mantri Gram Sadak Yojana (PMGSY) programme has induced a substantial shift of workers out of agriculture, but otherwise effected rather minor changes.

the price of those services is endogenous. As a robustness check, results are also derived for a required outlay of about 1.4 per cent of GDP.[3]

A related, important question is whether the social profitability of a given programme is sensitive to how it is financed. Taxation of use involves a wider base when the goods concerned are produced domestically. This motivates an analysis of an excise tax on good 2, which may be administratively feasible.

Another salient feature of public policy in such economies is the imposition, in the formal urban sector, of a regulated wage that lies above its market-clearing level. If, in the present structure, all producers of goods 2 and 3 are subject to this regulation, then there is no informal urban sector, and the associated assumption about the functioning of the labour market is quite strong. Since the scope of such regulation may affect the social profitability of a given roads programme, the variation in which the regulation can be enforced only in sector 2, leaving the wage in sector 3 fully flexible, is also analysed.

Small open economies are also subject to fluctuations in their barter terms of trade, where the border price of exports is notably more volatile than that of imports. Such stochastic fluctuations may well influence a programme's social profitability. Conversely, a programme may modify how strongly these exogenous shocks affect the allocation of resources. Both issues are treated, under the assumption that households are risk neutral.

The plan of the paper is as follows. The model is set out in Section 2. The conditions for equilibrium and the effects on welfare of a change in the public sector's net supply vector are treated in Section 3. The model is calibrated numerically and then employed to yield an exact welfare analysis in Section 4. Section 5 deals with alternative policies, Section 6 with stochastic shocks. The chief conclusions are drawn together in Section 7.

2 The model

The economy comprises a single city and its rural hinterland. The city serves as the hub for its international trade. If it lies in the interior, the port is little more than some docks and a customs house, whose claims on resources are neglected. A trunk route connects the port to the city. If the economy is landlocked, the city could lie on the main border crossing with some neighbouring country, through which all international trade must pass. More likely in practice, the city lies at some remove from the border. Goods 1 and 2 are tradable at the exogenous border prices p_1^* and p_2^*. If the economy is landlocked, these prices include any transportation costs and transit fees through its neighbour.

Households and firms are price-takers in domestic markets. Rural households are net producers of good 1. What they do not consume themselves, they sell to agents in the city, either for consumption by urban households or for export. Urban firms produce good 2, which is consumed by all households and also enters into the production of good 3. Like land in the rural sector, there is a specific, urban fixed factor, namely, capital, which is used in the production of good 2. Thus, both goods will be produced domestically. Good 3 comprises domestic transportation and storage services. Urban firms produce them by means of labour and good 2. They are sold to all users at the urban price. The endowments and technologies are such that, in equilibrium, good 1 is indeed exported and good 2 imported.

[3] 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 per cent.

The government must raise revenues to finance the provision of public goods, including the proposed rural roads programme. Its administrative capacities are such that it relies wholly on a tariff, t_2, on good 2.

The three locations—the border, rural hinterland, and city—are denoted by the index $k = 0,1,2$, respectively, and the price of good i in location k by p_{ik}. The domestic prices of goods 1 and 2 are tethered to world prices by arbitrage, domestic transport costs, and indirect taxes. Let the shipping of one unit of good i from location k to k' require $a_{i,kk'}$ $(= a_{i,k'k})$ units of good 3. Then 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 $a_{1,20} = 0$ if the city lies at the border. Rural households pay

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

for good 2. If the city lies in the interior, urban households and firms are subject only to transportation costs on the trunk route:

$$p_{12} = p_1^* - a_{1,20}p_{32}, \tag{3}$$

$$p_{22} = (1+t_2)p_2^* + a_{2,02}p_{32}. \tag{4}$$

The aggregate net private output of good i in location k is denoted by y_{ik}, with the convention that net inputs of goods have a negative sign. The foregoing assumptions imply $y_{12} = y_{21} = y_{31} = 0$.

Labour is mobile. Let the endowments and technologies be such that, in all allocations, some workers from rural households are engaged in urban production. They commute to urban jobs, paying fares and spending time in travelling.[4] If they buy goods in the city, the fact that such expenditures are made at urban prices is ignored.

The urban wage is regulated at $\underline{w}_2$, which exceeds the market-clearing level when rural workers can commute, so that rural households are effectively rationed. The rural wage rate, w_1, adjusts so as to bring about full employment.

2.1 The rural economy

Rural households are identical and supply their endowments of labour, $\bar{l}_1$, and land completely inelastically. They choose inputs of labour in the production of good 1 so as to maximize profits, thus yielding the derived demand for labour, $l_{11}(p_{11}, w_1)$, and hence the aggregate supply function $y_{11}[l_{11}(p_{11}, w_1)]$. Labour not thus employed is supplied to urban firms or the public sector. For each such unit supplied, the fraction τ_l is lost in travelling and the fare costs $a_{l,12}p_{31}$. Aggregate, net household income is

$$m_1 = p_{11}y_{11} + [(1-\tau_l)\underline{w}_2 - a_{l,12}p_{31})](\bar{l}_1 - l_{11}), \tag{5}$$

where rationing in the urban labour market implies $(1-\tau_l)\underline{w}_2 - a_{l,12}p_{31} > w_1$. Their aggregate final demand for good i $(= 1,2)$ is $x_{i1}(\mathbf{p}_1, m_1)$. Let $v_1(\mathbf{p}_1, m_1)$ denote their indirect utility function.

2.2 The urban economy

Urban households are also identical and supply their endowments completely inelastically. Firms rent capital, choosing inputs so as to maximize profits. Given constant returns to scale (CRS) in the production of goods 2 and 3, pure profits are zero in equilibrium. With capital fully employed, the derived

[4] Migration involves various complications, and is ruled out. The importance of commuting is inferred from Asher and Novostad (2020).

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:

$$p_{32} = \underline{w}_2 a_{l3} + p_{22} a_{23}, \tag{6}$$

where the unit input requirements of labour and good 2, a_{l3} and a_{23}, are fixed.

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:

$$m_2 = p_{22} y_{22} + \underline{w}_2 (a_{l3} y_{32} - z_{l1} - z_{l2}) - (1-\tau_l)\underline{w}_2 (\bar{l}_1 - l_{11}), \tag{7}$$

where $-z_{lk}\,(\geq 0)$ denotes the level of employment in the public sector at location k. Urban households' aggregate final demand for good i $(=1,2)$ is $x_{i2}(\mathbf{p}_2,m_2)$, and $v_2(\mathbf{p}_2,m_2)$ denotes their indirect utility function.

2.3 The public sector

Public sector firms trade at market prices. Let z_{ik} denote their net output of good $i\,(=1,2,3,l)$ at location k. The public sector's aggregate net supply vector, $\mathbf{z}$, comprises, *inter alia*, the bundle of net inputs needed to produce public goods.

The government balances its budget. Since private agents do likewise, it 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.

3 Equilibrium and welfare

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 with some programme of improvements. The difference $\Delta\mathbf{z} \equiv \mathbf{z}^2 - \mathbf{z}^1$ involves only the inputs required to construct and maintain those improvements.

3.1 Equilibrium

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 conditions for each tradable good at location k are

$$y_{11}(p_{11},w_1) + z_{11} = x_{11}(\mathbf{p}_1,m_1) + s_{1,12}, \tag{9}$$

$$s_{1,12} + z_{12} = x_{12}(\mathbf{p}_2,m_2) + s_{1,20}, \tag{10}$$

$$s_{1,20} + z_{10} = e_1, \tag{11}$$

$$s_{2,21} + z_{21} = x_{21}(\mathbf{p}_1,m_1), \tag{12}$$

$$y_{22}(p_{22},\underline{w}_2) + s_{2,02} + z_{22} = x_{22}(\mathbf{p}_2,m_2) + a_{23} y_{32} + s_{2,21}, \tag{13}$$

$$z_{20} = s_{2,02} + e_2. \tag{14}$$

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

$$y_{32} + z_{31} + z_{32} = a_{1,12}s_{1,12} + a_{l,12}s_{l,12} + a_{2,21}s_{2,21} + a_{1,20}s_{1,20} + a_{2,02}s_{2,02}. \tag{15}$$

It should be noted that the $s_{i,kk'}$ and $s_{l,12}$ are measured in tonne-km and passenger-km, respectively. When multiplied by the associated $a_{i,kk'}$ and $a_{l,12}$ and summed together, they yield the total demand for the inputs required to produce those services with the technology $y_{32} = \min(-a_{23}y_{23}, a_{l3}l_{32})$, augmented by public production $z_{31} + z_{32}$. An improvement in the network, in the form of a reduction in the $a_{i,kk'}$ and $a_{l,12}$, can result in both a reduction in y_{32} and an increase in total tonne-km and passenger-km. In what follows, the private output of transport services denotes the *input* index y_{32}, not the movements of goods and commuters that it makes possible.

The labour market clears at both locations:

$$\bar{l}_1 + z_{l1} = l_{11}(p_{11}, w_1) + s_{l,12} \tag{16}$$

and

$$\bar{l}_2 + (1 - \tau_l)s_{l,12} + z_{l2} = l_{22}(p_{22}, \underline{w}_2) + a_{l3}y_{32}, \tag{17}$$

It is seen from (1) - (4) and (6) that given the (endogenous) tariff 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 (17) and then m_2 from (7), followed by $\mathbf{x}_k(\mathbf{p}_k, m_k)$, $k = 1, 2$. The full solution—if one exists—is obtained by using by using (9) - (14) to yield $\mathbf{s}$ and $\mathbf{e}$. Obtaining all values in equilibrium therefore reduces to finding a positive pair (w_1, t_2) satisfying (8) and (15).

The pair (w_1, t_2) is determined by, *inter alia*, the parameters $\mathbf{a}_k, \mathbf{a}_{l,12}$, and $\mathbf{z}$, changes in which define the programme. Although obtaining closed-form results is out of the question, qualitative comparative static analysis is possible. Beginning with the tariff, if the programme expands international trade, then the tax base will expand and any increase in t_2 will be correspondingly smaller—or even turn negative. Since the wage is regulated, the programme will induce at most modest changes in employment and output in sector 2. It follows from (6) that p_{32} will also change little when production of transport services is not very intensive in good 2. This implies that the changes in the unit costs of shipping goods between locations are closely determined by the size of the changes in $\mathbf{a}_k$. On the farm, p_{11} will increase by approximately $(a^1_{1,12} - a^2_{1,12})p^*_1$ and p_{21} will decrease by approximately $(a^1_{2,21} - a^2_{2,21})(p^*_2 + t_2)$.

The port city is the simpler of the two settings to analyse. Let $z_{31} = z_{32} = 0$, so that (15) can be expressed as

$$y_{32} = a_{1,12}(y_{11} - x_{11}) + a_{2,21}x_{21} + a_{l,12}(\bar{l}_1 - l_{11}), \tag{18}$$

where $y_{11} - x_{11}$ is the level of the marketed surplus. The programme induces a fall in y_{32} directly by reducing $a_{1,12}, a_{2,21}$ and $a_{l,12}$, but it also induces changes in $y_{11} - x_{11}, x_{21}$, and commuting, $\bar{l}_1 - l_{11}$. Differentiating $y_{11} - x_{11}$ totally,

$$d(y_{11} - x_{11}) = dy_{11} - \nabla x_{11} \cdot (dp_{11}, dp_{21}, dm_1).$$

Since p_{11} increases, it follows from (5) and the envelope theorem that income increases. If, as is plausible, net income from commuting is small compared with that from cultivation, then $dm_1 \approx p_{11}dy_{11} + y_{11}dp_{11}$. Suppose further that cross-price effects in consumption are small (if preferences are Cobb-Douglas, they will be zero). Then

$$d(y_{11} - x_{11}) \approx \left(1 - p_{11}\frac{\partial x_{11}}{\partial m_1}\right) dy_{11} - \left(\frac{\partial x_{11}}{\partial p_{11}} - y_{11}\frac{\partial x_{11}}{\partial m_1}\right) dp_{11}.$$

Both goods are normal in consumption. Hence, the negative of the second term on the r.h.s is positive. The marginal expenditure propensity on good 1, $p_{11}\cdot\partial x_{11}/\partial m_1$, is less than 1, so that the first term on the r.h.s. is also positive if the output of good 1 increases. Since p_{11} increases, y_{11} will do likewise—unless w_1 also increases so strongly that p_{11}/w_1 falls.

The assumption that cross-price effects are small implies that x_{21} increases, income and substitution effects pulling in the same direction. Both $a_{l,12}$ and the scale of commuting are arguably small, so that changes in $a_{l,12}(\bar{l}_1 - l_{11})$ will almost surely be of second order. It then follows from (18) that the indirect effects of the programme work to increase y_{32}, unless there is a sufficiently large contraction of farm output. In the latter event, the programme's net effect would be to reduce y_{32}, and since employment in sector 2 changes little, a contradiction arises. The said effect is therefore ambiguous. Yet it is clear that the programme must induce a startling expansion of foreign trade if that is to overwhelm the direct effect of reducing $\mathbf{a}_k$ and $\mathbf{a}_{l,12}$. To sum up, a socially profitable programme is likely to induce rather small changes in the tariff, and a shift of rural labour from employment in transportation to work on the farm. A similar argument holds when the city lies in the interior; for transport costs on the trunk route are affected only by changes in p_{32}, which will be small.

3.2 Welfare

Let the arguments of the social welfare function, Ω, be v_1, v_2 and the public goods produced by $\mathbf{z}^1$, namely, $g(\mathbf{z}^1)$.

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

This separability makes the marginal rate of substitution between the utility indices v_1 and v_2 independent of $\mathbf{z}$. Given the assumption that the difference $\Delta\mathbf{z} \equiv \mathbf{z}^2 - \mathbf{z}^1$ involves only the inputs required by the programme, the latter involves no changes in g and so yields the change in welfare:

$$\Delta\Omega = \Delta W = W[v_1(\mathbf{p}_1^2, m_1^2), v_2(\mathbf{p}_2^2, m_2^2)] - W[v_1(\mathbf{p}_1^1, m_1^1), v_2(\mathbf{p}_2^1, m_2^1)]. \tag{19}$$

Expressing (19) in terms of money-metric utility, let Δm_k^e be 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: Δm_k^e satisfies $v_k(\mathbf{p}_k^1, m_k^1 + \Delta m_k^e) = v_k(\mathbf{p}_1^2, m_k^2)$. Let the marginal social valuations placed on v_1 and v_2 be the same.[5] 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).

Now, v_k is homogeneous of degree 0 in m_k and $\mathbf{p}_k$. When calculating the EV, imposing the form $v_k = m_k/\kappa_k(\mathbf{p}_k)$, where $\kappa_k(\mathbf{p}_k)$ is the (Könus) cost-of-living index, involves neither strong assumptions on preferences nor additional parameters. Then

$$\Delta m_k^e = m_k^1 \cdot \left(\frac{m_k^2}{m_k^1} \cdot \frac{\kappa_k^1}{\kappa_k^2} - 1 \right),\ k = 1, 2, \tag{20}$$

where the programme almost surely induces m_k and κ_k to move in opposite directions.

For urban households, the effects are likely to be nearly offsetting. To prove this claim, recall that the induced change in the tariff will be rather small. By the envelope theorem, the change in m_k is approximately $\Delta p_{22} \cdot y_{22}^1$, the wage being fixed. In the port-city setting, $\Delta p_{22} = \Delta t_2$; in the interior setting, $\Delta p_{22} = \Delta t_2 + a_{2,02}\Delta p_{32}$, where the change in p_{32} is surely smaller still. Since $m_2^1 = p_{22} \cdot y_{22}^1 + \underline{w}_2(\bar{l}_2 - l_{22}^1)$,

[5] Allowing them to differ will obscure the comparisons that follow. In practical applications, there may well be good reasons for them to take different values.

the ratio m_2^2/m_2^1 must be close to 1. The same holds for κ_2^1/κ_2^2, but in the opposite direction; for p_{12} is unchanged in the port-city setting, and it scarcely changes, in response to Δp_{32}, when the city lies in the interior.

4 Numerical examples

The qualitative results obtained in Section 3.1 are useful but limited. To make further progress, a resort to numerical examples is unavoidable. In the nature of the model, the calibration is rather stylized. Various robustness checks serve to buttress the findings.

4.1 Calibration

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

Let the technologies for producing the tradable goods exhibit constant returns to scale (CRS) and be Cobb-Douglas in form. Then the aggregate supply functions are

$$y_{ik}(p_{ik}, w_k) = \left[A_i \left(\frac{\alpha_i p_{ik}}{w_k} \right)^{\alpha_i} \right]^{1/(1-\alpha_i)}, \quad i = k, i = 1, 2, \tag{21}$$

where α_i is the elasticity of the output of good i w.r.t. labour, and the contribution of the fixed factor is absorbed into the TFP parameter A_i. Transportation services are produced under CRS by means of labour and good 2, with the fixed unit input vector $\mathbf{a}_3 = (0, 0.2, 0, 1)$.

Households' preferences are also Cobb-Douglas, with b_{ik} denoting the taste parameter for good i at location k. The aggregate final demand for good i at k is $x_{ik} = b_{ik} m_k / p_{ik}$.

The public sector employs only labour, without the programme in the amount $-z_{l2}^1$, which can be thought of as providing some bundle of public goods, including the maintenance of the current network. The programme requires additional public employment in the amount $\Delta z_l = -z_{l2}^2 + z_{l2}^1$, which leaves the provision of the said bundle unchanged.

The complete set of parameters is set out in Table 1. By definition, y_{11} and y_{22} are net of their respective own-input requirements. In peasant agriculture, industrial inputs—agrochemicals, machine services, and diesel fuel—account for a small fraction of total costs, and are ignored. Thus, $p_{11}y_{11}$ and $p_{22}y_{22}$ are value added, respectively. 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: let $\alpha_{2l} = 0.7$.[6]

The population is assumed to be quite rural; those households possess 65 per cent of the economy's total endowment of labour ($\bar{l}_1 = 1.3, \bar{l}_2 = 0.7$). Let them have a relatively strong taste for their own output. In variant 1, $b_{11} = 0.6, b_{21} = 0.4$. Urban households' tastes for good 1 are a bit weaker: $b_{12} = b_{22} = 0.5$.

The demand for transport services is derived from the movements of goods and commuters. By assumption, the quantity thereof needed to ship one unit of good i from k to k', $a_{i,kk'}$, is fixed in each state of the network. The cost of shipping a tonne-km on the trunk route from the border to the inland city is surely

[6] 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 $\alpha_{2l} = 0.7$.

much lower than than that on the tracks in its hinterland, and agricultural commodities are typically relatively bulky for their weight. Much of the hinterland, moreover, will be far removed from the city. These considerations suggest the following pattern: for each good, unit shipping requirements are twice as high on the tracks as on the trunk route, and twice as high for good 1 as for good 2. To be specific, $a_1^1 = (0.2, 0.05), a_2^1 = (0.1, 0.025)$. The costs of commuting are assumed to arise mainly from the time involved: $(\tau_l^1, a_{l,12}^1) = (0.1, 0.01)$.

Table 1: Constellation of parameter values

Parameter	Value	Description
Rural		
A_1	4.0	TFP parameter, good 1
$\boldsymbol{\alpha}_1$	$(0.5, 0.5)$	elasticity of output w.r.t. labour and land
$\mathbf{b}_1$	$(0.6, 0.4)$	taste parameters
$\bar{l}_1$	1.3	labour endowment
a_1^1	$(0.2, 0.05)$	unit transport requirement, without programme
a_1^2	$(0.1, 0.05)$	transport requirement, with programme
$(\tau_l^1, a_{l,12}^1)$	$(0.1, 0.01)$	commuting time and fare components, without programme
$(\tau_l^2, a_{l,12}^2)$	$(0.05, 0.005)$	commuting time and fare components, with programme
Urban		
A_2	1.65	TFP parameter, good 2
$\boldsymbol{\alpha}_2$	$(0.7, 0.3)$	elasticity of output w.r.t. labour and capital
$\mathbf{b}_2$	$(0.5, 0.5)$	taste parameters
$\bar{l}_2$	0.7	labour endowment
a_2^1	$(0.1, 0.025)$	unit transport requirement, without programme
a_2^2	$(0.05, 0.025)$	unit transport requirement, with programme
$\mathbf{a}_3$	$(0, 0.2, 0, 1)$	unit input requirement, sector 3
$\underline{w}_2$	1.91	regulated wage in urban and public employment
Public sector		
$\mathbf{z}^1$	$(0, 0, 0, -0.05)$	net output vector, without programme
$\mathbf{z}^2$	$(0, 0, 0, -0.07)$	net output vector, with programme
$\mathbf{p}^*$	$(1, 1)$	border prices of goods 1 and 2

Note: for the port city, $a_{1,20} = a_{2,02} = 0$. Also, $A_2 = 1.75, \underline{w}_2 = 1.8$.

Source: author's elaboration.

The values of the parameters A_1 and A_2, which encompass the endowments of the respective fixed factors, and the level of the regulated wage must satisfy two conditions: first, that good 1 be exported and good 2 imported, and second, that there be some rural–urban commuting. When the city lies in the interior, these hold comfortably when $A_1 = 4, A_2 = 1.65$ and $\underline{w}_2 = 1.91$. Producers of good 2 in the inherently different port-city setting enjoy no 'natural' protection from distance. In their relief, let $A_2 = 1.75$, aided by the lower regulated wage of 1.8.

In the *status quo*, the public sector employs 2.5 per cent (= 0.05/2) of the workforce. Let the programme demand an additional 1 per cent, whose associated cost, with workers paid the regulated wage, amounts to 0.8 and 1 per cent of the *status quo* GDP in the port- and interior-city settings, respectively. The programme is assumed to halve $\mathbf{a}_1^1, \mathbf{a}_1^2$ and $(\tau_l^1, a_{l,12}^1)$.[7] The assumption that the tariff on good 2 is the sole source of government revenue may make some programmes of government expenditures infeasible.

In a variant of the above constellation, households' tastes for the imported good are stronger. The parameter values $b_{11} = 0.5, b_{21} = 0.5$ and $b_{12} = 0.4, b_{22} = 0.6$, respectively, constitute variant 2 of the

[7] Ahmed and Nahiduzzaman (2016), for example, estimate that rural roads in Bangladesh reduce the costs of transporting goods and passengers by 35 per cent and 65 per cent, respectively.

base case. The programme's cost, expressed as a percentage of GDP, is virtually identical to that in variant 1.

4.2 Status quo allocations

The salient magnitudes arising in the *status quo* allocation when the city is a port and when it lies in the interior, respectively, are set out in Table 2. These suffice for some auxiliary calculations. GDP, for example, is the sum of value added in sectors 1, 2, and 3, and wage payments by the public sector.

Table 2: Key magnitudes in equilibrium—a tariff on good 2

Variant	y_{11}	l_{11}	p_{11}	w_1	y_{22}	l_{22}	p_{22}	y_{32}	p_{32}	e_1^a	t_2
Status quo 1											
Port city	4.252	1.130	0.594	1.118	0.974	0.433	1.143	0.370	2.029	0.629	0.143
Interior city	4.305	1.159	0.460	0.854	0.866	0.398	1.254	0.379	2.161	0.477	0.200
Programme 1											
Port city	4.523	1.278	0.797	1.410	0.942	0.413	1.127	0.238	2.025	0.992	0.127
Interior city	4.540	1.288	0.677	1.194	0.787	0.398	1.204	0.294	2.151	0.889	0.150
Status quo 2											
Port city	4.195	1.100	0.597	1.139	0.842	0.352	1.074	0.479	2.015	1.216	0.074
Interior city	4.229	1.118	0.465	0.880	0.696	0.291	1.142	0.523	2.138	1.076	0.089
Programme 2											
Port city	4.512	1.272	0.798	1.416	0.850	0.356	1.078	0.300	2.015	1.612	0.078
Interior city	4.640	1.246	0.679	1.217	0.701	0.294	1.145	0.388	2.139	1.453	0.092
Programme 2A											
Port city	4.299	1.155	0.697	1.297	0.877	0.373	1.093	0.394	2.019	1.354	0.093
Interior city	4.300	1.156	0.571	1.063	0.727	0.310	1.164	0.457	2.143	1.210	0.111

Note: ^{a} $\mathbf{p}^*\mathbf{e} = 0$ and $p_i^* = 1$ imply $e_1 + e_2 = 0$.
Variant 1: $b_{11} = 0.6, b_{21} = 0.4$; $b_{12} = b_{22} = 0.5$; the programme reduces $\mathbf{a}_i^1$ by one half.
Variant 2: $b_{11} = b_{21} = 0.5$; $b_{12} = 0.4, b_{22} = 0.6$; the programme reduces $\mathbf{a}_i^1$ by one half.
Variant 2A: the programme reduces $\mathbf{a}_i^1$ by one quarter.
Source: author's calculations.

Taking variant 1 first (see the first panel of Table 2), GDP in the port-city setting is 4.398, the sectoral shares in which are 57.5, 25.3, and 15.2 per cent, respectively, with the public sector contributing the remaining 2.0 per cent. Almost 15 per cent of the output of good 1 is exported. Employment on the family farm, at 1.13, accounts for 86.9 per cent of the rural labour endowment. The rest find urban jobs, thus making up the difference between $l_{22} + a_{l3}y_{32} - z_l^1$ and $\bar{l}_2 = 0.7$, albeit 10 per cent of their time is spent in travelling. Rural households are, moreover, strongly rationed in the urban labour market; for the market-clearing wage in the hinterland, w_1, is only 62 per cent of the regulated wage. The latter results in a correspondingly high price of transport services. The farm-gate price of good 1 is just 59.4 per cent of its border price. The tariff on good 2 is 14.3 per cent; transportation costs in the hinterland increase its farm-gate price to 1.346.

The corresponding allocation in the interior-city setting is broadly similar, where it should be recalled that the value of A_2 has been chosen a little smaller, and that of the regulated wage a bit higher, than in the port-city setting. GDP is somewhat smaller, at 3.887, with sectoral shares of 50.9, 27.9, and 18.7 per cent, respectively. Exports of good 1 are just 11.1 per cent of domestic output, and this narrower base implies a higher tariff—of 20 per cent. This pattern reflects the intrinsically higher transport costs when the city lies in the interior, whereby the 'natural' protection of sector 2 is offset by a still higher level of the 'natural' hurdle facing exporters of good 1. Employment on the family farm is a little higher, at 89.2 per cent of the rural labour endowment. Rationing in the urban labour is yet more intense: w_1 is a mere 44.7 per cent of the regulated rate. The price of transport services is 6.5 per cent higher than in the port-city setting, with effects that ramify through all prices. The farm-gate price of good 1 is just 46 per cent of its border price. The price of good 2 at the farm gate is a stiff 1.47. Urban households face the more modest level of 1.254, but they can purchase good 1 at 0.892, as arbitrage brings its level below the border price of 1.

In variant 2, the economy is more import intensive, and hence more open. The ratio of exports to GDP is 0.279 in both city settings, and the tariff rates are correspondingly much lower and much the same, at 7.4 and 8.9 per cent in the two city settings (see the second panel of Table 2). The rural allocations are close to those in variant 1, but the levels of domestic production of good 2 are somewhat smaller. This stems from the higher derived demand for transportation services, and hence the labour needed to produce them. Shipments of good 2 to the rural hinterland are higher, which must be matched by greater shipments of good 1 for export.

4.3 Allocations with the programme

The general argument in Section 3.1 indicates that the programme's postulated effect of halving rural–urban unit transportation requirements will bring about a substantial improvement in rural households' producer (equals consumer) price of good 1, p_{11}, and their consumer price of good 2, p_{21}. That argument also establishes that the marketed surplus, $y_{11} - x_{11}$, will normally increase substantially, and if this increase is not largely absorbed in the city, then exports must rise substantially, too, thus inducing a wider tax base. With their workers fully employed and paid the regulated wage, urban households are affected only by changes in the tariff and, if the city lies in the interior, in transport costs on the trunk route. Those costs also change only with the tariff, good 2 entering into the production of transport services. Since the wage is regulated, the price of those services, p_{32}, may not change much.

Executing the programme results in the allocations set out in Table 2. The reallocation of resources is extensive in both variants and city settings. As expected, the output of good 1 increases somewhat, with the attendant result that the economy becomes strikingly more open. In the port-city setting of variant 1, the ratio of exports to GDP increases by one third, from 0.143 to 0.190; when the city lies in the interior, by fully one half, from 0.123 to 0.188. By Walras's law and $p_1^* = p_2^* = 1$, any increase in exports of good 1 must be matched by the same increase in imports of good 2, thus widening the tax base and relieving the pressure on the tariff. Indeed, the programme is, in a sense, self-financing; for despite its heavy cost, it induces a modest fall in t_2 in the port-city setting and a substantial one when the city lies in the interior. As for the composition of GDP, labour is reallocated from urban to rural production, with a strong rise in w_1 and a sharp fall in commuting, work on the farm now accounting for 98.3 per cent of rural households' labour endowment in the port-city setting and 99.1 per cent in the interior setting. Whereas the output of transport services falls by 36 and 28 per cent in the two settings, respectively, the movements of goods increases substantially, of good 1 by 25 and 42 per cent, respectively. The output of good 2 falls only slightly in the port-city setting, but by 9 per cent when the city lies in the interior.

The ratio of exports to GDP also increases somewhat, even in the inherently more open-economy variant 2—from 0.279 to 0.310—so that the tariff barely rises, from 7.4 to 7.8 per cent in the port-city setting and from 8.9 to 9.2 per cent in the interior-city setting. The output of good 2 scarcely changes, but that of transport services contracts as strongly, in proportional terms, as in variant 1.

4.4 Welfare analysis

With Cobb-Douglas preferences, $v_k = m_k/(p_{1k}^{b_{1k}} p_{2k}^{b_{2k}})$. Recalling assumption 1, we obtain the following values for the port-city setting in variant 1: $W^1 = 3.396 + 1.491$ and $W^2 = 3.844 + 1.487$. Rural households are a good deal better off with the programme, urban households are slightly worse off. In order to calculate the EV, we must find a Δm_k^e such that $(m_k^1 + \Delta m_k^e)/\kappa_k(\mathbf{p}_k^1) = v_k^2$. Equation (20) yields $\Delta m_1^e = 0.369$ and $\Delta m_2^e = -0.004$. Their sum, 0.365, is the EV, which is 8.3 per cent of the *status quo* GDP.

When the city lies in the interior, the 'natural' protection afforded to producers of good 2 is affected by the programme only through any resultant change in the price of transport services. Arbitrage induces a rise in the farm-gate price of good 1: the increase of 45 per cent is accompanied by an increase of 86 per cent in exports. The resulting widening of the tax base is so large that t_2 falls by a quarter, to 0.15.

As for the EV, $W^1 = 3.032 + 1.572$ and $W^2 = 3.509 + 1.564$. Proceeding as before, $\Delta m_1^e = 0.349$ and $\Delta m_2^e = -0.009$. Hence, the EV is 0.340, where it should be noted that A_2 and $\underline{w}_2$ are also at work, albeit their values in the two settings differ little.

The corresponding results for variant 2 are as follows. In the port-city setting, $W^1 = 3.237 + 1.467$ and $W^2 = 3.762 + 1.467$. Then, $\Delta m_1^e = 0.458$ and $\Delta m_2^e = 0.000$, yielding EV = 0.458, or 10.5 per cent of the *status quo* GDP. When the city lies in the interior, $W^1 = 2.867 + 1.522$ and $W^2 = 3.394 + 1.522$. Then, $\Delta m_1^e = 0.418$ and $\Delta m_2^e = -0.000$, yielding EV = 0.418, or 10.8 per cent of the *status quo* GDP.

As argued in Section 3.2, the programme has virtually no effect on urban welfare. This invariance results from full employment at a regulated wage when there are only minor changes in the tariff rate, and hence also in the price of transport services, which matters when the city lies in the interior. Yet this also holds for variant 1 when the city lies in the interior, wherein the tariff falls from 0.20 to 0.15, and p_{22} from 1.254 to 1.204. That urban households are intensive consumers of their own output provides them with some compensation for the lower producer (equals consumer) price.

To assess the sensitivity of these values to changes in the programme's cost and technical efficacy, suppose the investment requirements were 75 per cent higher than those assumed above, i.e. $-(z_{l2}^2 - z_{l2}^1) = 0.035$, or 1.43 per cent of the *status quo* GDP in the port-city setting in variant 1. The EV would be 0.318, or 12.9 per cent, smaller. The corresponding value for the interior-city setting would be 0.307, or 9.7 per cent, smaller. In variant 2, the values would be 0.375 and 0.348, respectively, or 18.1 and 16.7 per cent smaller, respectively. The more open economy of variant 2 involves a larger transportation and storage sector, so that heavier demands for labour by the programme involve higher opportunity costs indirectly.

As for technical efficacy, a given level of investment may yield diverse reductions in the unit transport requirements for the rural–urban movement of goods and commuting. Suppose the reduction in those requirements were one quarter instead of one half, a sub-variant denoted by A. This programme is fiscally infeasible in variant 1A, the tax base provided by the tariff alone being too narrow when the investment's yield is so modest. It is just feasible when obtaining that yield requires an input of 0.018 units of labour instead of the reference level of 0.02. This result illustrates one aspect of the interplay between the programme's technical characteristics and how it is financed.

There are no such problems in variant 2A, wherein stronger tastes for good 2 ensure an adequate tax base. The corresponding values of the EV in the port- and interior-city settings are 0.214 and 0.203, respectively, as opposed to 0.458 and 0.418 when the programme yields a reduction of one half. These results indicate mildly increasing returns in social profitability to achieving greater technical efficiency through reductions in $\mathbf{a}_i^1$.

5 Alternative policies

The foregoing findings rest on particular fiscal and regulatory policies. Do they also hold, by and large, under alternatives that are likely to be adopted in practice?

5.1 Taxation

That taxes on international trade are attractive when administrative capacity is weak applies equally to exports. Yet an export tax has a fundamental drawback. It lowers the net price received by producers, and thus operates much like a higher cost of transporting output to the city. Financing a roads programme by means of an export tax is therefore, in some measure, self-defeating; for—in contrast to a tariff on the importable—it narrows the tax base.

Poll taxes are arguably a political non-starter. Workers in regulated employment can be brought within the net of direct taxation, but governments are wary of provoking urban unrest. When capital is a fixed factor, a tax thereon is effectively lump-sum in nature, but in practice, the yield is also limited. Turning to the rural sector, land taxes are politically troublesome, even when there are good cadastral records. Rural households also keep few if any accounts, thus ruling out income taxes. Imposing excise taxes on their outputs—good 1 in the present setting—is likewise infeasible.

That leaves an excise tax on good 2, τ_2, as a promising practical alternative to a tariff thereon, where the tax base is now total domestic use. Excises on imports are readily levied, in the same way as a tariff. Domestic production occurs only in the city, much of it at a fairly limited number of identifiable plants, at whose gates tax inspectors can make their collections. Users pay the cum-tax border price $p_2^* + \tau_2$ plus transport costs, if any. Domestic producers do not enjoy the subsidy t_2 conferred by the tariff. With competition from importers, they receive the net price p_2^* in the port-city setting; if the city lies in the interior, then p_2^* plus the unit transport cost from the border.

The effects of this alternative tax are illustrated for variant 2A. The allocations in both city settings are set out in the first panel of Table 3. In keeping with intuition, the economy is more open than its counterpart under the tariff, as is seen by comparing the allocations with those in Table 2. Exports are greater and the tax rate is lower ($\tau_2 < t_2$). The transport sector is correspondingly larger, and without the protective tariff, sector 2 is smaller. Employment on the farm is somewhat larger.

Table 3: Key magnitudes in equilibrium—policy variations

Variation	y_{11}	l_{11}	p_{11}	w_1	y_{22}	l_{22}	p_{22}	y_{32}	p_{32}	e_1^a	τ_2
Excise: good 2											
Status quo 2A											
Port city	4.296	1.154	0.598	1.114	0.713	0.277	1.043	0.505	2.009	1.363	0.043
Interior city	4.303	1.157	0.467	0.869	0.576	0.222	1.107	0.556	2.131	1.212	0.053
Programme 2A											
Port city	4.435	1.229	0.698	1.260	0.713	0.277	1.056	0.420	2.011	1.542	0.056
Interior city	4.402	1.211	0.573	1.041	0.576	0.222	1.122	0.492	2.134	1.382	0.068
Flexible w_3											t_2
Status quo 1											
Port city	4.257	1.133	0.674	1.266	0.920	0.399	1.116	0.401	1.632	0.781	0.116
Interior city	4.325	1.169	0.622	1.151	0.707	0.298	1.150	0.470	1.551	0.851	0.112
Programme 1											
Port city	4.527	1.281	0.824	1.456	0.933	0.407	1.122	0.241	1.762	1.033	0.122
Interior city	4.560	1.300	0.755	1.325	0.735	0.315	1.169	0.307	1.633	1.043	0.128

Note: [a] $\mathbf{p}^*\mathbf{e} = 0$ and $p_i^* = 1$ imply $e_1 + e_2 = 0$.
Variant 2A: $b_{11} = b_{21} = 0.5$; $b_{12} = 0.4, b_{22} = 0.6$; the programme reduces $\mathbf{a}_i^1$ by one quarter.
Source: author's calculations.

In contrast to the tariff regime, the programme induces an increase in τ_2, the tax base being already quite wide and the *status quo* rate low. With the urban wage regulated, the programme leaves activity in sector 2 unchanged, since it has no effect on the trunk route when the city lies in the interior. The substantial contraction of transport services leaves more rural workers on the farm. The output of good 1 is correspondingly higher.

In the port-city setting, $W^1 = 3.251 + 1.437$ and $W^2 = 3.505 + 1.427$. Then, $\Delta m_1^e = 0.219$ and $\Delta m_2^e = -0.011$, yielding EV = 0.208, or 4.86 per cent of the *status quo* GDP. This outcome differs from that under a tariff, in that urban households suffer a slight but not wholly negligible loss. When the city lies in the interior, $W^1 = 2.869 + 1.495$ and $W^2 = 3.130 + 1.483$. Then, $\Delta m_1^e = 0.206$ and $\Delta m_2^e = -0.012$, yielding EV = 0.194, or 5.14 per cent of the *status quo* GDP. The location of the city itself has a rather small influence on the programme's contribution to welfare. The small losses suffered by urban households stem from the absence of tariff protection, so that the quasi-rents from capital, which accrue wholly to those households, fall.

5.2 A flexible transport wage

Imposing a regulated wage on the private, organized sector of the economy, here represented by sector 2, 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. In the extreme, the wage paid to transport workers could be completely flexible, like that ruling in the rural sector. Indeed, the two rates would then be closely connected, with equilibrium governed by the condition that w_3 be equal to w_1 plus the cost of commuting to such a job: $w_3 = w_1(1 + \tau_l) + p_{32}a_{l,12}$.

This policy variation is examined for variant 1. The key magnitudes in equilibrium are set out in the second panel of Table 3. Comparing them with their counterparts under regulation of both sectors 2 and 3 (see the first panel of Table 2), the economy is much more open, with higher levels of exports and lower tariffs in both city settings, both with and without the programme. Transport activity is correspondingly higher, too, especially in the *status quo*. With w_3 closely tethered to w_1, the price of transport services is much lower when both are flexible, even though w_1 is higher than under full regulation. These wage rates and the tariff have rather modest effects on production in sector 1, but exert a substantial influence on most other quantities.

Under this looser regulatory regime, the programme induces a small increase in the tariff, that rate being lower in the *status quo* allocations, wherein exports are greater than their levels under full regulation. In the interior-city setting, rural–urban commuting almost ceases: only 0.00036 of the rural endowment of 1.3 are underway.

In the port-city setting, $W^1 = 3.535 + 1.392$ and $W^2 = 3.911 + 1.431$. Then, $\Delta m_1^e = 0.327$ and $\Delta m_2^e = 0.041$, yielding EV = 0.368, or 8.1 per cent of the *status quo* GDP. This outcome is virtually identical in aggregate to that under full regulation, but differs in that urban households enjoy a small gain. When the city lies in the interior, $W^1 = 3.398 + 1.319$ and $W^2 = 3.727 + 1.384$. Then, $\Delta m_1^e = 0.275$ and $\Delta m_2^e = 0.067$, yielding EV = 0.342, or 8.1 per cent of the *status quo* GDP. The location of the city has a rather small influence on the programme's contribution to aggregate welfare, but whereas urban households are almost unaffected under full regulation, they do gain somewhat under looser regulation. They get all the jobs that pay the regulated wage, and the changes in prices that result from the lower price of transport services more than offset the loss of income that results from some urban workers earning only w_3 instead of $\underline{w}_2$. For their part, all rural–urban commuters now earn w_3 instead of $\underline{w}_2$.

These comparisons with Section 4.4 involve economies saddled with two distortions, namely, a distortionary tax and a regulated wage. On the face of it, a tariff is worse than an excise tax. In the numerical examples, the value of the welfare index W is indeed inferior under the tariff, but only slightly so, be the city at the border or in the interior. The associated EV is also inferior, but also only by a slender margin. Urban households do slightly worse under the excise tax. The programme's effects on aggregate welfare under a tariff are insensitive to whether the wage in the transport sector is regulated, but urban households do gain somewhat when it is not.

6 Random shocks

Small open, largely rural economies are subject to external shocks in the form of fluctuations in their barter terms of trade and internal ones in the form of fluctuations in rainfall and the prevalence of pests. The social profitability of a roads programme generally depends on the character of the stochastic environment; conversely, it may also change how the economy responds to such fluctuations. Extending the foregoing structure to address these issues involves various complications. A brief discussion serves as a preliminary to an analysis of a tractable case.

Beginning with fluctuations in the barter terms of trade, the choice of good 2 as numéraire implies that the border price of good 1 becomes the variate P_1^*, whose realization p_1^* is not known when rural households must take their production decisions at the start of the agricultural cycle.[8] Suppose consumption decisions can be postponed until p_1^* is revealed, along with income from cultivation. This does not resolve matters; for although, in the absence of natural shocks, the output of good 1 is perfectly certain once inputs of labour have been chosen, the subsequent shipment of goods depends on p_1^*. The same holds, *mutatis mutandis*, for good 2, for the tariff is now a random variable. It follows that the labour market cannot clear at the start of the cycle as it does under certainty; for the derived demand stemming from the level of transport services later on is stochastic. To deal with this difficulty fully would require each period to be divided into two sub-periods reflecting the agricultural cycle, with a planting season followed by a harvest season. Such an extension will not be attempted here.

In the presence of natural shocks, the output of good 1 is no longer certain, thus further complicating matters.

6.1 Random border prices

The following assumptions serve to make the analysis tractable. First, let all agents be risk neutral. While this assumption is admittedly strong, it permits direct comparisons with the EV under certainty. Second, let P_1^* be binomially distributed, taking the values $1-\delta$ and $1+\delta$, with probabilities q and $1-q$, respectively.

The third assumption concerns how rural households form expectations about the wage and the price of output when maximizing expected profits. Output is fixed independently of the realized value p_{11} by the earlier choice of l_{11}. In the favourable event that $P_1^* = 1+\delta$, rural income will be high, but good 2 will be relatively cheap for all households. If the two goods are sufficiently good substitutes for the latter effect to outweigh the former, then exports, and hence also imports, must be correspondingly larger than when $P_1^* = 1-\delta$. This implies that the demand for transport services, with its derived demand for labour, is larger in the favourable outcome. For the whole allocation to be feasible *ex post*, the employment of labour in producing goods 1 and 2 and all public goods, whose levels are chosen *ex ante*, must not exceed the economy's total endowment less the derived demand for labour arising from the resulting level of transport services. This motivates the following assumption:

Assumption 2 *Let rural households form the expectation $\mathbb{E}W_1$ and all producers the associated, rational expectation of output prices, conditional on the tariff rate ruling for each realization of P_1^*, such that when $P_1^* = 1+\delta$, the labour market just clears and the government's budget is balanced (equivalently, $\mathbf{p}^*\mathbf{e} = 0$).*

It remains to specify what happens when $P_1^* = 1-\delta$. Under the foregoing assumptions about income and substitution effects, there must be unemployment, since the labour market just clears when $P_1^* = 1+\delta$.

[8] In this section only, an upper case denotes a variate, its lower case, a particular realization thereof.

The resulting loss of income reduces the domestic demand for both tradable goods, and since the levels of output are fixed, the economy runs a balance of payments surplus, which accrues to the government as a budget surplus in the form of foreign exchange ($\mathbf{p}^*\mathbf{e} > 0$). In order to accommodate what would otherwise be a stochastically growing stock of such reserves, it would be necessary to extend the model to include, for example, other programmes and their financing. That will not be undertaken here. The valuation of the surpluses within the present framework is addressed below.

6.2 A numerical example

To illustrate the evaluation of a programme in the presence of random border prices, let variant 2 exhibit $P_1^* \in \{0.9, 1.1\}$, each outcome with probability 0.5. The allocations for the port and inland cities for each realized border price of good 1 are set out in Table 4. All satisfy assumption 2, together with the corollary that exports and transport services are greater when $P_1^* = 1.1$, and that there is unemployment and a budget surplus when $P_1^* = 0.9$.

Beginning with the port city, the support of P_{11} slightly exceeds 2δ both with and without the programme. The difference arises from the lower tariff when $P_1^* = 1.1$, where the tariff and the non-random border price of good 2 determine the support of P_{22}, namely, $[1.065, 1.095]$. Since good 2 also enters into the production of transport services, but the regulated wage is fixed, P_{32} also has a narrow support.

Table 4: Key magnitudes in equilibrium—random border prices, variant 2, port and interior cities

	y_{11}	l_{11}	p_{11}	$\mathbb{E}W_1$	y_{22}	l_{22}	p_{22}	y_{32}	p_{32}	e_1^a	t_2
Port city											
Status quo											
$P_1^* = 0.9$	4.148	1.075	0.496	1.151	0.853	0.358	1.095	0.450	2.019	1.136	0.095
$P_1^* = 1.1$	4.148	1.075	0.697	1.151	0.853	0.358	1.065	0.494	2.013	1.262	0.063
Programme											
$P_1^* = 0.9$	4.490	1.260	0.698	1.423	0.855	0.360	1.092	0.289	2.018	1.529	0.092
$P_1^* = 1.1$	4.490	1.260	0.899	1.423	0.855	0.360	1.068	0.310	2.014	1.672	0.068
Interior city											
Status quo											
$P_1^* = 0.9$	4.228	1.117	0.364	0.880	0.625	0.250	1.163	0.509	2.143	1.090	0.109
$P_1^* = 1.1$	4.228	1.117	0.566	0.880	0.625	0.250	1.125	0.565	2.135	1.211	0.072
Programme											
$P_1^* = 0.9$	4.500	1.263	0.579	1.209	0.626	0.250	1.159	0.382	2.142	1.478	0.106
$P_1^* = 1.1$	4.500	1.263	0.780	1.209	0.626	0.250	1.131	0.415	2.136	1.574	0.077

Note: $\delta = 0.1$. [a] When $P_1^* = 1.1$, $\mathbf{p}^*\mathbf{e} = 0$ implies e_2.
Variant 2: $b_{11} = 0.5, b_{21} = 0.5; b_{12} = 0.4, b_{22} = 0.6$.
Soure: author's calculations.

As under certainty, the programme promotes international trade, in part by reducing the demand for transport services, thus releasing labour to work on the farm. A concomitant, endogenous effect is a strong increase in the expected wage $\mathbb{E}W_1$. In this stochastic environment, the programme also narrows the difference between the output of transport services in the two states, as well as that in the tariff rate. The same qualitative conclusions apply when the city lies in the interior.

Welfare analysis

The first step is to calculate $v_k(P_1^* = 0.9)$ and $v_k(P_1^* = 1.1)$, with and without the programme. With risk-neutral agents and $q = 0.5$, the programme yields the expected gain

$$\mathbb{E}[\Delta V_k] = 0.5\left\{[v_k^2(P_1^* = 0.9) + v_k^2(P_1^* = 1.1)] - [v_k^1(P_1^* = 0.9) + v_k^1(P_1^* = 1.1)]\right\},\ k = 1, 2.$$

The alternative is to receive the sure thing Δm_k instead of the programme. Households in location k are indifferent between these two alternatives when Δm_k satisfies

$$\Delta m_k = 2\mathbb{E}[\Delta V_k]\left(\frac{1}{\kappa_k(P_1^* = 0.9)} + \frac{1}{\kappa_k(P_1^* = 1.1)}\right)^{-1}, \; k = 1,2.$$

For the port city, we have

$$\Delta m_1 = [(4.001 + 3.469) - (3.461 + 2.916)]\left(\frac{1}{0.802} + \frac{1}{0.940}\right)^{-1} = 0.473$$

and

$$\Delta m_2 = [(1.412 + 1.495) - (1.453 + 1.412)]\left(\frac{1}{1.013} + \frac{1}{1.079}\right)^{-1} = 0.022,$$

which yield $\Delta m_1 + \Delta m_2 = 0.495$. The corresponding value under certainty is 0.458.

For the interior city,

$$\Delta m_1 = [(3.636 + 3.043) - (3.107 + 2.461)]\left(\frac{1}{0.708} + \frac{1}{0.871}\right)^{-1} = 0.434$$

and

$$\Delta m_2 = [(1.459 + 1.527) - (1.460 + 1.483)]\left(\frac{1}{0.998} + \frac{1}{1.070}\right)^{-1} = 0.023,$$

which yield $\Delta m_1 + \Delta m_2 = 0.457$. The corresponding value under certainty is 0.418.

The budget surpluses that accrue when $P_1^* = 0.9$ must also be brought into the reckoning. For the port city, the surpluses with and without the programme are 0.036 and 0.078, respectively. These arise with probability 0.5 and though small, are not negligible: 0.5×0.078 is 2 per cent of GDP. As for placing a value thereon to go with $\Delta m_1 + \Delta m_2$, if lump-sum transfers were possible, it would be correct to add the expected value of the (algebraic) difference, i.e. $0.5 \times (0.036 - 0.078) = -0.021$, yielding 0.474 as the value of the improvement in welfare. If such transfers are impossible, there will be a premium on public income; but 0.021 is only 4.2 per cent of 0.495, so that the exact treatment of the surpluses does not materially alter the calculation. The corresponding magnitudes when the city lies in the interior are $0.5 \times (0.063 - 0.107) = -0.022$ and 0.435, respectively.

It is noteworthy that, even after the adjustment for the budget surpluses, the values of the improvement in welfare are greater than their counterparts under certainty. Now, the theory of the firm yields the result that profits are strictly convex in prices, so that expected profits with varying prices exceed profits when the mean values of prices always rule. The argument applies, *mutatis mutandis*, to risk-neutral households in the present setting. If they were risk averse, the strict concavity of the functions v_k in income would pull in the opposite direction, with an ambiguous outcome. Any aversion to risk would, of course, influence the whole allocation, an exploration of which is not undertaken here. Yet these offsetting forces suggest that introducing risk aversion may well lead to results that differ rather little from those obtained under certainty.

7 Conclusions

Ambitious rural roads programmes seek, in effect, to restructure the economy, and they involve correspondingly large investments. By improving the rural sector's terms of trade, they promote trade, not only domestically, but also with the rest of the world, which has important fiscal consequences when there is a heavy reliance on indirect taxes. The scale of the resulting changes in prices and the allocation of resources is such that a rigorous evaluation of their social profitability calls for a general equilibrium analysis.

To sum up the findings of the foregoing theoretical and numerical analyses, first, the social profitability of a given roads programme, as measured by the resulting aggregate equivalent variation, is rather insensitive to various, salient features of the economy: (i) the location of the city in relation to the border; (ii) whether the programme is financed by a tariff or an excise on the importable; (iii) whether a regulated wage can be imposed on all urban firms, or only with the exception of those producing transportation; and (iv), when agents are risk neutral, whether the economy's external barter terms of trade fluctuate stochastically. Secondly, that aggregate measure of welfare largely reflects what happens to rural welfare. Urban households experience changes that range from mildly adverse to mildly favourable, depending on the particular combination of taxation and the scope of wage regulation. They gain when border prices fluctuate.

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