South African road surfacing policy, international oil price changes, and the shadow pricing of costs and benefits

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1. Introduction

Writing in the *Business Day* on 2 October 2007, economics journalist Hilary Joffe notes that "it was not long ago that there was a famine of infrastructure investment [in South Africa]; now there's a feast, with each new week bringing reports of new projects and new, much higher estimates of the totals to be spent in years to come." Joffe expresses enthusiasm about this, for reasons with which we agree:

> The infrastructure feast has already helped to raise SA's investment ratio to nearly 21% of gross domestic product, from a low of below 15% just five years ago. We are already seeing the beginnings of a shift from consumption-driven to investment-driven growth that the economy needs if it is to grow on a sustainable basis. And of course much of that infrastructure is already urgently needed; and the need will grow as economic growth takes place.

However, she is immediately led to ask two pressing questions. First, "even if these are all good and necessary projects, can SA's economy afford them … all at the same time?" And second, "is anyone counting the total cost to the economy and puzzling out which projects should take priority, and whether some should wait (or be dropped altogether)?"

Since the launching of ASGISA and other elements of the Government's infrastructure push in 2004, one of us has pointed out in national media on a number of occasions that the administrative structures behind the push do not facilitate coordinated dynamic optimization of the overall expenditure. This is exacerbated by the looming shadow of the 2010 FIFA World Cup, a milestone event that concentrates project deadlines into a bottleneck and distorts the intertemporal distribution of costs of scarce construction inputs. Put simply, the large short-term increase in demand for materials and (especially) limited supplies of engineering and project-management skills significantly affects their prices. Furthermore, because they will fear a retrenchment of official commitment after 2010 has come and gone, investors who capitalize the infrastructure push will discount future returns increasingly highly the closer we get to the milestone.

The point here is by no means to suggest that we should abandon the infrastructure initiative. As Joffe says, if we want to try to shift to a higher plateau of equilibrium-trend growth, there is probably no better use we could make of the Government's carefully accumulated fiscal strength and credibility.[1] The point, rather, is that we will waste more of these resources than necessary if we are not strategic with their investment. As it progresses, the infrastructure push changes the background conditions against which national departments, provinces, municipalities and parastatal agencies plan and budget. Therefore, planning and budgeting practices need to adjust in a coordinated way, not just once but progressively and continuously. This is the main aspect of what economists mean by 'dynamic optimization'.

In this paper we discuss one specific aspect of such optimization as it applies to roads.

Roads constitute the single largest component of the actual and planned infrastructure allocation, constituting roughly one-quarter of the budgeted expenditure through 2010. The budget of South African National Roads Agency Ltd (SANRAL) has increased from R2, 1 billion in 2005-06 to a projected R11, 5 billion in 2009-2010. Outside of this amount, R3 billion has been allocated toward rural roads through the Provincial Infrastructure Grant for the Expanded Public Works Programme (EPWP). National government has set aside an additional R9 billion for municipal transport, roads and precinct upgrading specifically relating to 2010. Municipalities and provinces spend further amounts on roads as aspects of integrated projects (e.g., port enhancements) funded separately. Finally, SANRAL raises funds from tolling and Build-Operate-and-Transfer (BOT) schemes that are reinvested in roads. (BOT revenues alone are forecast to reach an eventual steady state of R20 billion.)

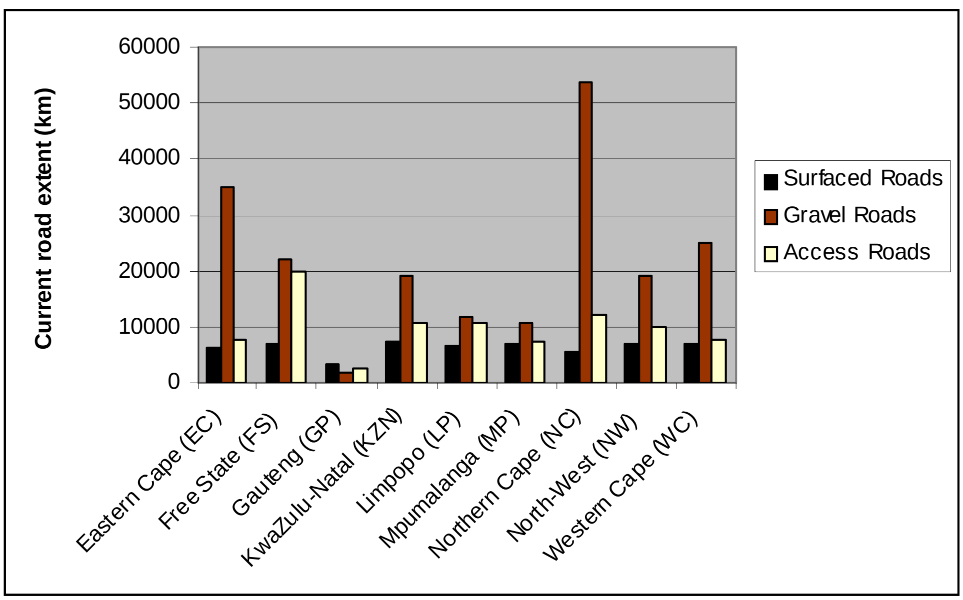
Given all of these inputs, administered from multiple points and subject to varying disciplines regarding annual rollover, it is difficult to specify exactly what proportion of total investment is presently flowing into road construction, upgrading and maintenance. The most useful magnitude to try to discern, in our view, is the recent historical growth rate in aggregate investment by all tiers of government plus SANRAL. Our best estimate, taking into account a range of over a dozen official and industry sources, is that if current budget targets on the Medium Term Expenditure Framework (MTEF) are met (and allocated funds are successfully invested in actual roads), the total annual investment as of 2010 will be about seven times the comparable figure for 2000 (before adjusting for inflation). Based on data from the latter year, Ross (2001) calculated that a four-fold increase in the investment level at that time was required to prevent the country's road network from irretrievably collapsing. Thus we think it is safe to conclude that the current rate of investment, if maintained, will not only restore the value of the network that was lost during an earlier period of neglect, but will expand its value. However, as Ross's four-fold multiplication target was reached only in 2005-2006, we must suppose that current investments are still recovering asset values lost during the decade of neglect in the 1990s. This allows us to understand the otherwise confusing talk from the Minister of Transport in 2007 of a R50 billion "backlog" in national road maintenance even on the current budget. We do not think it should be inferred from this that current MTEF allocations are too low. It is doubtful that national capacity exists for expanding investment levels more quickly in any case, at least without self-defeating effects on input costs.

[1] This would not be true if we thought that we could fix the public education system by throwing more money at it. But we don't think that lack of funds is what ails SA's schools.

However, our opinion that the total road budget is approximately economically correct does not license the conclusion that it is being optimized. Our aim in this paper is to focus attention on *one* major source of inefficiency in its present use, namely sub-optimal proportional investment in low volume bitumen sealed roads compared with gravel roads.

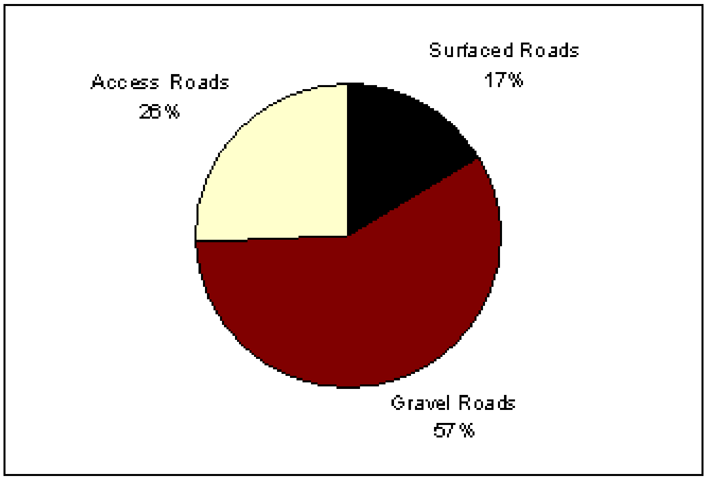
SA's 18,000 km of national roads (that is, roads administered by SANRAL) are surfaced. However, four-fifths of the remaining 530,000 – 550,000 km of 'proclaimed' (provincial and municipal) roads is unsurfaced. There are an additional 221,000 km of unproclaimed access roads, made of gravel or earth, not falling within the official maintenance responsibility of any tier of government. Figures 1 and 2 provide a visual summary. While this proportion of unsurfaced roads is not high by African standards, it is more than we find in other countries with per capita GDPs similar to SA's. We will argue that there are strong economic reasons for thinking that many of these roads, at least among those made with gravel rather than dirt, should be upgraded to bituminous pavement. Other gravel roads, and most dirt roads, should not presently be maintained at all except where a community is crucially dependent on them for basic mobility, or where a road can be entirely maintained by local labour with no public contribution beyond workers' salaries.

Figure 1: SA's provincial and municipal road network



Data Source: NDoT 2001

Figure 2: SA's Road Surfaces



Data Source: NDoT, 2001

We will defend this recommendation despite acknowledging significant increases in the price of bitumen, driven by the general spike in the world cost of petroleum products since early 2005. To be sure, these increases have stressed road budgets. The Gauteng Department of Public Transport, Roads and Works reported in 2005 that the cost of upgrading a gravel road to a low volume sealed road had increased by 67% since 2004, and the cost of upgrading to a standard paved road had increased by 48% in the same period. As long as the world price of petrol keeps rising, each Rand of additional investment must upgrade construct or fewer kilometers, at least unless very substantial new efficiencies can somehow be found. We believe it to be almost certain that the trend increase in the world price of petroleum, spurred by unprecedented growth in several of the world's largest countries (especially China), will continue for at least the next five years.[2] Thereafter, it *may* begin to level off *if* advanced economies see large-scale replacement of petroleum-burning equipment (particularly vehicle engines) by devices that consume other fuels. We do not think anyone is in a position to know how efficiently markets, if assisted by economically wise tax policy, will prove able to bring about this outcome.

However, the point that surfaced roads are becoming more costly, and will go on becoming more costly over the near term, should not be confused with the idea that construction and maintenance of surfaced roads has become significantly more expensive *relative to* properly maintained gravel roads. It is often assumed that because bitumen is a petroleum product, it must inevitably become a relatively worse option compared to gravel and cement when the world oil price rises. This reasoning tends naturally to lead to the conclusion that the *proportion* of unsurfaced roads to be upgraded and the *proportion* of new surfaced roads – as opposed to the *totals* that can be afforded from a fixed budget –

[2] Such a trend increase is consistent with temporary drops.

should both be reduced from what they otherwise would be. In this paper, we will indicate why this reasoning is mistaken, and indeed has the case backwards. If the pace of recent increase in road construction and upgrading is slowed due to dearer petrol, this reduction should be disproportionately expressed as reduced investment in those gravel roads that are not chosen for sealing or more extensive re-surfacing.

Around the world, a standing assumption prevailed for many years that urban streets and provincial and national highways should be paved, and that the default materials for all other roads should be dirt and gravel. Gradually over the past decade or two, however, a more sophisticated understanding of the value of infrastructure assets has overturned the traditional view. The goal of this paper is to survey the basis of this understanding, and apply it to the specific circumstances of SA.

It is crucial to be clear about we mean in this report by a ‘surfaced road’. It is obvious simply from consideration of traffic volumes that it would never be rational to operate an unsurfaced national road. Our discussion is therefore restricted to consideration of comparatively low-volume roads. Occasionally we will compare costs of constructing and maintaining ‘full’ (i.e., standard Hot Mix Asphalt) bitumen roads with costs of constructing and maintaining gravel roads, simply to dramatize the extent of the latter under some circumstances. However, our focus in general should be understood as being on two choices faced by road authorities: (1) between surfacing an existing gravel road versus maintaining it as unsurfaced, and (2) between constructing a new road with a bitumen surface versus a graded aggregate surface. In the case of (2), low-volume sealed roads can be constructed using several methods, including surfacing over existing alluvial sand or over new gravel bases. Where the former method is possible the latter will generally be more expensive. Thus we will generalize our analysis by comparing gravel road costs with costs of sealed roads on aggregate bases.

The paper is organized as follows. Section 2 reviews traditional methods for guiding surfacing decisions, and outlines their limitations in the context of current South African conditions. Section 3 examines the comparative impact of rising petroleum costs on both bitumen and gravel surfaced roads. Section 4 considers the effect of discounting and of anticipating inflation on choices between road types. Section 5 describes other currently operative factors, especially including shadow-priced factors that are pushing up the cost of gravel surfaces disproportionately to those of bitumenous surfaces. Section 6 focuses on a specific aspect of these asymmetric forces, namely optimization of SA’s labour resources and optimal investment in development of the national stock of human capital. Section 7 concludes and offers an executive summary.

2. Comparative evaluation of road investments

It was once orthodoxy in development economics that the key requirement of non-mature economies is accumulation of the stock of capital. One continues to find strong traces of this former orthodoxy in the rhetoric of policy debate in SA. Its basis is not altogether misplaced. SA clearly has a large pool of unskilled and semi-skilled labour resources that are not productively employed, or that are under-employed by comparison with what they would produce if they were in some other countries (e.g., Asian ones). It is plausible to suppose that these resources could be more productively employed if they could be matched with a larger supply of capital – including basic infrastructure such as roads.

However, the idea that 'piling up' capital stock is necessarily the royal path to development ceased to be conventional wisdom in economics thirty years ago. As evidenced by a variety of cases from the first two decades of policy in post-colonial economies, accumulating capital assets can make a country poorer instead of richer if the opportunity costs of these assets is higher than their rate of return (Dinwiddy & Teal 1996, chapter 5). Whenever a decision or policy leads to a stream of benefits and costs, we should endeavour to evaluate the stream in terms of other possible flows we could have had instead had we made an alternative decision about how to dispose of the resources. It is simply not true that building up capital stock is always the best use of a country's money, raw materials, or administrative and professional expertise. This point is especially relevant in SA today, when we confront a shortage of managerial and engineering skills, and our extracted commodities find rising prices on world export markets due to growth in the 'BRIC'[3] and other developing countries.

In the case of public infrastructure, benefits accrue by flowing over some period of time. If periodic maintenance of an asset is required, as with roads, then the same is true for some portion of the costs. The moment we set out to estimate opportunity costs over time, we must discount future values by the difference we attach between having the benefits and paying the costs now, and deferring them. A common approach is to set the discount rate by reference to the difference between the interest rate earned by a safe financial asset and the expected medium-term rate of inflation. In SA it is currently customary to benchmark this at 8%. There are then two ways in which we can economically test a possible investment:

(1) The discount rate captures the opportunity cost of capital. In a sound investment, this must be less than the discount rate at which the present value of benefits and costs are equal. The second quantity is referred to as the internal rate of return (IRR).
(2) We subtract the discounted costs from the discounted benefits so as to estimate the net present value (NPV) of the contemplated investment. This is the most direct way of comparing two types or instances of an asset, such as a given new or improved gravel road and a given new or improved paved road: which has the higher NPV? It is immediately obvious that this form of comparison must be highly sensitive to the period of time over which we choose to estimate costs and benefits. One asset might pile up costs earlier than another but then deliver a better ratio of benefits to costs at later stages. How many of these later stages are factored into the calculation of NPV will then crucially influence the conclusion of our comparison.

Comparative evaluations of projects based on IRR and NPV often agree. However, where they do not, NPV should always be favoured for public-sector investments, because the public sector is the part of the economy with the longest time horizon and the most secure access to capital given uncertainty. Uncertainty about the future price of petroleum beyond

[3] This common acronym stands for 'Brazil, Russia, India, China'. Smaller oil-exporting countries such as Saudi Arabia and Venezuela are also contributing to rising prices of complementary commodities that SA sells.

the next five years makes this point directly relevant to comparisons of currently contemplated road projects in SA.

The key to proper economic analysis of any investment decision is finding a way to account for all consequences that have value to people or impose costs on them, even where the values and costs in question don't have prices assigned to them directly by markets. Such non-traded cost and benefit streams must be assigned so-called 'shadow prices', that is, monetary amounts people would apparently – on the basis of systematic inference from data – be willing to pay to avoid the costs and acquire the benefits if a market for them existed. Shadow prices and relationships between them are calculated on so-called 'social accounting matrices' (SAMs), based on methods originally developed in classic work by Little and Mirrlees (1974). Their general framework was subsequently developed into practical instruments for use in comparatively evaluating specific projects by type, including road projects.

With reference to roads as investments in development, SAM-based comparisons can be made at two levels: between road projects and other infrastructure projects, and amongst alternative road projects. The National Department of Transport's Road Infrastructure Strategic Framework (RISFSA) cites World Bank research into comparative economic rates of return from infrastructure investment in Bank-funded projects around the world over the period 1974 to 1992. Table 1 gives average rates of return on types of investments. The average return on infrastructure projects in general was 16%. Road infrastructure returns were highest among all categories, earning an average over the total period of 24.5%.

Table 1: Average economic rates of return on World Bank-supported projects

SECTOR	**1974 to 1982**	**1983 to1992**
	Percentage	
Irrigation and drainage	17	13
Telecommunications	20	19
Transport	18	21
Airports	17	13
Roads	20	29
Ports	19	20
Railways	16	12
Power	12	11
Urban Development		23
Water and sanitation	7	9
Water supply	8	6
Sewerage	12	8
Infrastructure	18	16
All Bank operations	17	15

Source: RISFSA 2002

For purposes of making comparisons amongst alternative possible road projects, the World Bank has developed two commonly used SAM-based instruments, reviewed in Lebo and Schelling (2000). The Highway Design and Maintenance Standards Model (HDM-III) (World Bank 2005) takes into account surface deterioration and shadow-priced user costs, while the Roads Economic Decision Model (RED) (World Bank 2004) also factors in the shadow-priced level of expected service to road users and considers the potential of adequately maintained roads to influence nationally aggregated growth.

Three important considerations limit the practical usefulness of these instruments in prioritizing road investments in SA:

1. The shadow pricing of public costs and benefits is a generalised, estimated input derived from data on least-developed countries (LDCs). Though this can be adjusted to apply to middle-income developing countries such as SA, this procedure is not likely to yield accurate values for countries – like SA – that have large regional variations among labour markets.
2. The HDM-III model bases recommendations on surfacing alternatives exclusively on exogenously fixed relationships between traffic volume thresholds and maintenance frequencies. For reasons discussed later, these relationships have become increasingly sensitive to changes in various shadow-priced costs and benefits, especially those related to environmental considerations.
3. South Africa's urban-rural wealth differential is significantly larger than that of almost every other country. HDM-III and RED *can* be parameterized to capture costs and benefits associated with accelerated urbanisation and redistributional objectives. However, in SA, given its extreme conditions with regard to inequality, these hand adjustments tend to swamp the influence of other elements of the models, thus partly negating the point of relying on them (Ross 2001); one therefore might as well build a nationally customized model to begin with.

The benchmark HDM-III guideline is that, in most cases, average annual daily traffic (AADT) levels in excess of 200 to 250 vehicles are required to justify the upgrade of an unpaved road to a paved surface (World Bank 2005). The RED model does not clearly address distinctions between the suitability of paved and unpaved surfaces (World Bank 2004).

The SADC Guideline on Low-Volume Sealed Roads (SADC 2003) introduces a new approach of customised road design to correspond to local climates, particular natural materials located in project vicinities, and particular transport needs specific to Southern Africa. The Guideline document identifies cases from the region where sealing gravel surfaces at AADT thresholds of less than 100 is economically justified.

Similarly, the South African National Department of Transport's Road Infrastructure Strategic Framework (2002) does not attempt to specify a rigid surfacing algorithm, but instead simply specifies factors relevant to judging best surfaces. It prescribes attention to key performance indicators listed and described in Table 2.

Table 2: South African Strategic Framework performance indicators

Performance Indicator	**Description**
Serious casualty crashes	The number of crashes, involving hospitalisation or death per year (normalised per 100 000 head of population).
Road fatalities	Crash fatalities per year (normalised per 100 000 head of population).
Persons hospitalised	Persons hospitalised per year as a result of crashes (normalised per 100 000 head of population).
Road maintenance effectiveness	A cost index reflecting the proportion of the road network that is being maintained to target conditions and the expenditure per km required.
Smooth travel exposure	The proportion of travel undertaken each year on roads with roughness conditions less than the specified levels.
Greenhouse gas emissions	Gross emissions of CO2 calculated from fuel sold for road use and appropriate emission factors.
Traffic noise exposure	Arithmetic average of sound levels exceeded for 10% of each of the eighteen hours between 6.00am and midnight on a normal working day.
Return on construction expenditure	The percentage distribution of programmed expenditure by benefit cost ratio (BCR) range.
Actual travel time	The aggregation of travel times actually achieved per km on a representative sample of arterial roads and freeways.
Congestion indicator (urban)	The aggregation of delay per km on a representative sample of arterial roads and freeways in the urban metropolitan area.
User cost distance (passenger car)	The operating costs per km of a standard passenger sedan.
User satisfaction index.	Index of users' qualitative evaluation of satisfaction with road system outcomes. Also measured for freight and courier users.
Consumption of vehicle fuel [CVF].	Average rate of fuel consumption over time.

Source: NDoT 2002

While we think it would be a fool's errand to try to represent these indicators in a single deterministic formula for surfacing decisions claimed to guarantee economic optimality,[4] we nevertheless suggest that they can be put to systematic use. In Section 5 we will use them to guide selection of values associated with roads that call for shadow pricing when alternative surfaces are under consideration.

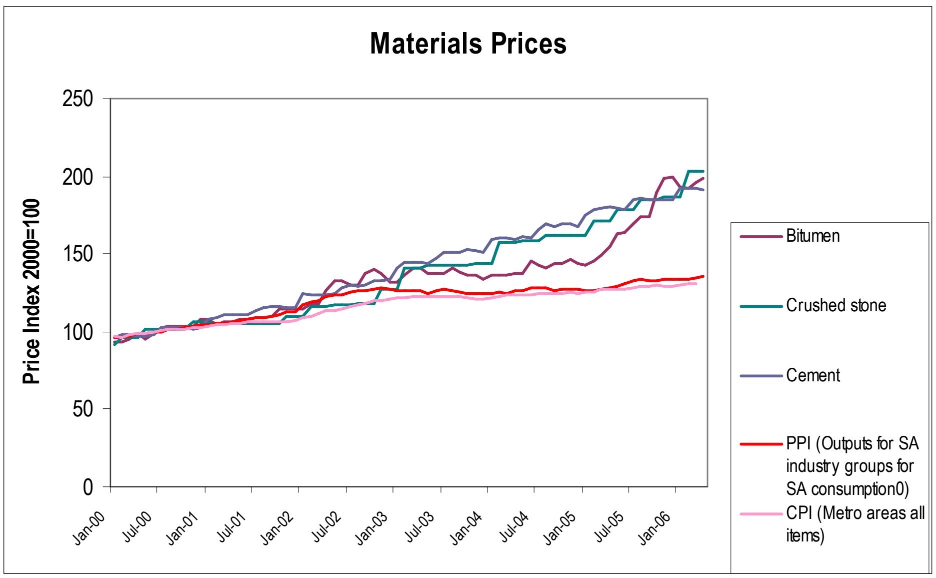
[4] This should not be confused with rejection of the idea of constructing formulae from the indicators for the sake of practical baseline or heuristic comparisons. SABITA's 'Supersurf' software (SABITA 2005) implements one such formula. The Supersurf manual is careful to emphasize its intended heuristic value; it should complement rather than supplant experienced human judgment.

3. Petroleum price impacts on surfacing decisions

The global economy is now in its third consecutive year of high oil prices by historical standards. As noted earlier, this is almost certainly the beginning of at least a decade-long pattern of increase. In this section we consider the impact of this continuing expected increase on the economics of surfacing decisions.

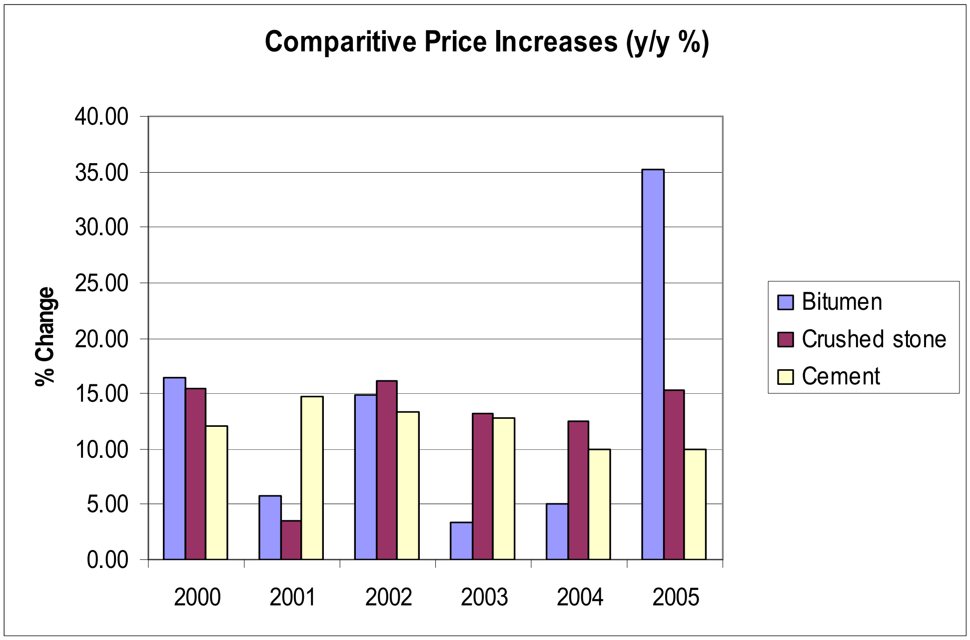
For most of the past six years, the price of gravel has risen faster than real inflation in SA, while bitumen price increases have been sub-inflationary. However, bitumen prices began rising faster than inflation about two years ago. Figures 3 and 4 show these relationships:

<u>Figure 3: Relative bitumen and gravel prices, 2000-2006</u>



Source: StatsSA

Figure 4: Comparative year-on-year price increases, bitumen and gravel, 2000-2005



Source: StatsSA

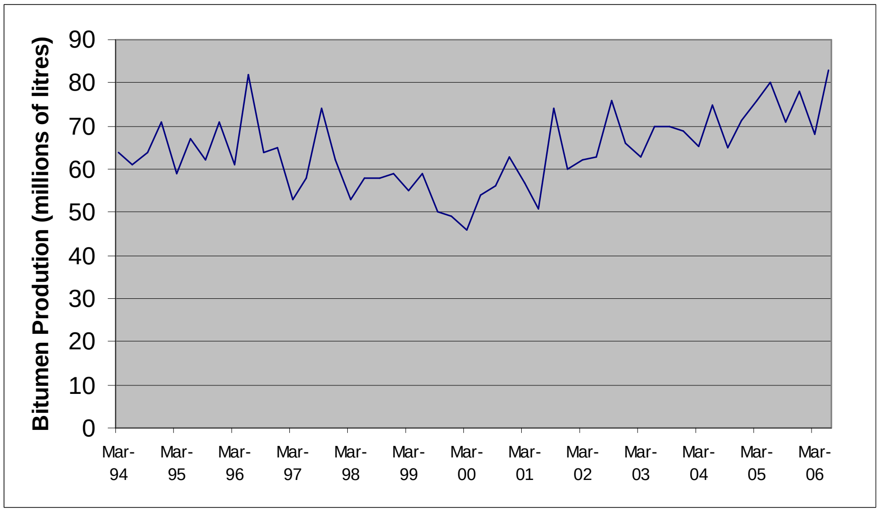
The rise in the relative price of bitumen corresponds closely to the most recent period of sharply rising global oil prices. Superficially, this might appear to confirm the inference that as oil becomes dearer, surfacing proportions on new roads should shift away from bitumen in favour of gravel, and fewer gravel roads should be re-surfaced.

However, as we will show in this and subsequent sections, the relative costs of bitumen and gravel *roads* are not simply, or even mainly, functions of the relative costs of the two basic materials. Furthermore, the trend relationships indicated in Figures 3 and 4 cannot be extrapolated unless it is supposed that local proportions of bitumen and gravel supply can be expected to remain roughly constant. We turn first to showing why this expectation would be false.

In connection with the strategic infrastructure push, and in particular with major time-phased initiatives such as 2010 stadium projects, the Gautrain, airport expansions, and Eskom's capacity upgrade, Government has solicited medium-term supply projections from suppliers of major construction inputs, including bitumen and gravel.

90% of SA's bitumen, all of which is refined locally from crude oil residue, is used in Government-funded transport infrastructure projects including road and rail works. Industry representatives (SABITA 2007) have assured Government that SA has sufficient refining capacity to meet the increased demand entailed by the infrastructure push, and that larger supply can be achieved by increasing the percentages of residual crude oil that are processed into bitumen[5]. Figure 5 below also indicates the relatively steady local supply of bitumen over the last twelve years, notwithstanding the extreme variance in world petroleum prices over that period. Suggestions for measures to secure future continued supply include investment in increased storage capacity, with accompanying environmental sustainability programmes.

Figure 5: South African bitumen production, March 1994 – July 2006



Source: Time Series Explorer 2006

With respect to gravel supply, SA produces up to 2000 kg of aggregate per capita, which falls short of the typical per capita quantities produced in developed countries, despite the fact that unsurfaced roads are much smaller proportions of their total road networks.[6] However, the relevant issue is not whether SA *could* produce adequate gravel to maintain current proportions of construction and maintenance under the accelerated investment regime – industry representatives are surely correct in giving reassurance to Government in this regard (Deane 2006b). The relevant questions instead revolve around supply elasticities given changes in two sets of prices: the price of fuel for haulage as a complement to gravel, and shadow prices of externalities associated with expansion of gravel harvesting and gravel use. We take up the latter in section 5. Here we focus on supply and price elasticity with respect to changes in petroleum prices.

A first, general, observation is that over the last twelve years, gravel supply has fluctuated with significantly greater volatility than bitumen, as Figure 6 indicates. Furthermore, the recent trend is one of decline.

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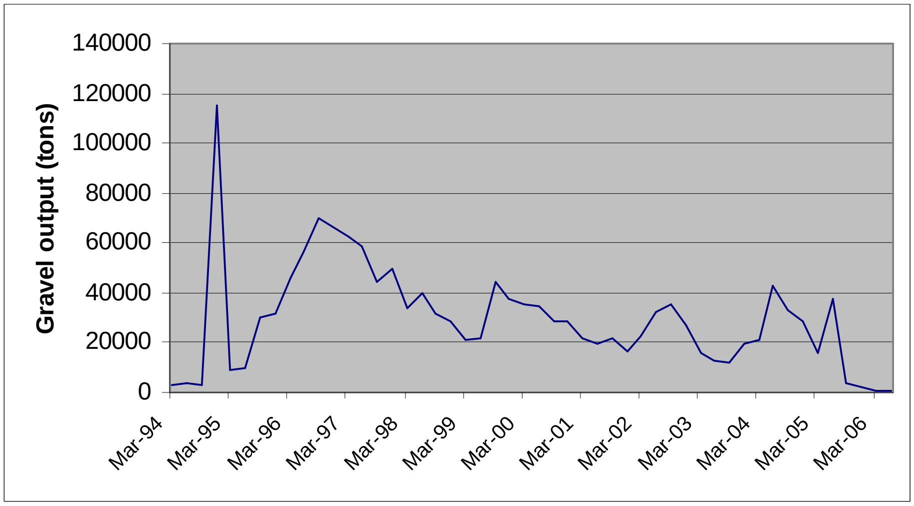
[5] Such residue from crude oil refining as is not processed into bitumen is further processed to be sold, both domestically and abroad, as bunker fuel.
[6] The USA produces 10000 kg per capita and the UK 5000 kg (Deane, 2006a).

Figure 6: SA gravel output, March 1994 - July 2006



Source: Time Series Explorer 2006

Comparisons of output trends in themselves say nothing about which changes in variables are driving them. The twelve-year period captured in the comparison between Figures 5 and 6 ranges over a break in world oil price trends, with low and steady or falling prices up to early 1999, and higher but steady or rising prices (before inflation) after early 1999. During 1997-1998 gravel supply fell sharply while bitumen supply wandered around a close anchor to its trend line and the world oil price fell. Following the break, bitumen supply trends slightly upwards.

Aggregate comparisons among trends fail to capture two crucial aspects of the relationships between changes in world oil prices and the economics of road surfacing decisions. First, basic materials are far from the largest cost component of initial construction outlays for either surfaced or gravel roads. In the case of bitumen roads, costs of labour, machinery, surveying, paint and other inputs make up a minimum of 75% of total construction *and* maintenance costs. By contrast, the largest cost component by far in construction and maintenance of gravel roads is haulage. Gravel is heavy and must be carried in trucks running on petroleum (generally diesel) fuel. For maintenance of SA's current extent of gravel roads, about 30 million cubic metres of aggregate material are required to be hauled each year. At current distances between borrow pits, this is costing about 30 million litres of fuel. An additional 10 million litres is used for blading by motor graders. This amounts to about 0.1% of total SA diesel fuel consumption. This expenditure, unlike increased expenditure on bitumen, mainly occurs beyond year 1 of a road project, due to the need to replace gravel attrition (see Section 5). Thus the proportional impact of rising petrol prices on road construction costs goes steadily upward for gravel relative to bitumen as time horizons are extended. To the extent that rising petrol prices are expected to be a negative external shock on road budgets, their proportionate impact on surfaced road prices is highly sensitive to the discount rate on public investment.

SA's petroleum supply is imported. Thus, since petroleum is a larger proportion of future-discounted maintenance costs for gravel than for bitumen-surfaced roads, exchange-rate fluctuations play a more significant role in calculating the NPV of an unsurfaced than of a surfaced road. This raises a major complicating factor for economic analysis because, as demonstrated by Essama-Nssah *et al* (2007), a rising world oil price exerts a significant downward impact on the value of the Rand. In addition, because the Rand is heavily traded its exchange-rate value is highly volatile, giving rise to uncertainty risk as a factor in calculating NPV for any public investment that implies a stream of future costs of imported material. Furthermore, rising world oil prices positively affect world exchange-rate volatility (Hau 2002). Thus the world oil price, the exchange rate uncertainty risk, and the exchange rate itself, are all endogenously related. This greatly complicates any effort to calculate the NPV of a project, such as construction of a new gravel road, for which expected future costs include petrol as a substantial component; small adjustments in any one of the three endogenously related variables can produce large changes in estimates through their influence on the other two and through resulting feedback-driven amplification.

In the face of this uncertainty, we resort to simulation based on extrapolation from data during a recent period of rising oil prices (2005-2006). We make no attempt to consider possible mutual feedback between oil price increases and Rand depreciation, except to remind the reader of this possibility. Later, we will consider some additional factors that could invalidate the extrapolation. An important fact about these influences is that, like currency depreciation, they all tend to exaggerate the difference between the expected costs of surfaced and unsurfaced roads, increasing the relative opportunity cost of the latter. Thus quantitative uncertainty need not imply qualitative uncertainty.

We consider the impact of oil price changes on a low-volume road with a gravel base and a bitumen seal. Savings in future maintenance costs for this type of road, relative to an unsealed one, principally arise through the fact that the seal prevents gravel from being blown and washed away and needing to be replaced by freshly hauled aggregate. The quantitative parameters used in our simulation are given in Table 3. Relationships among the parameters are based on construction cost estimates from SABITA and diesel and bitumen price estimates from the Department of Minerals and Energy (2006) and Colas (2007). We begin by assuming an entirely unrealistic haulage distance of 100 km. This is simply for ease of calculation; we must generate enough simulated observation points to isolate the ratios between oil-price-driven cost components and total costs, and real cost magnitudes don't matter at this stage. Later, when we factor in other cost components that vary between road types, we will plug these ratios into realistic haulage distance values.

Table 3: Sample parameters for low-volume bitumen-sealed road

1km BITUMEN low volume road

bitumen input (m³):	**12**
length (m)	1000
width (m)	6
spread (l / m²)	2
input (l)	12000

Distance hauled (km):	***100***

diesel consumption - base on site

	diesel (litres/ton/km)	volume hauled (tons)	**diesel consumption (l)**
bitumen haulage	2.5	12	**30**

	diesel consumption (l)	
bitumen application	0.5	*1 pass at 0,5l per pass on a kilometre road*

Total Diesel consumption - base on site (l)

application	0.5
haulage	3000
TOTAL	***3000.5***

diesel consumption - including construction of base

	diesel (litres/m³/km)	volume hauled (m³)	**diesel consumption (l)**	
bitumen haulage	2.5	12	**30**	
haulage of aggregates	3.8	60	**228**	*stones spread over surface (60m³ per 1km road)*
haulage of gravel base	0.044	450	**19.8**	

	diesel consumption (l)
bitumen application	**0.5**
base- reshaping	**2.5**

Total Diesel consumption - including construction of base (l)

application	3
haulage	27780
TOTAL	***27783***

Based on these parameters, Table 4 shows impacts on gravel road construction and undiscounted maintenance costs for selected pairs of bitumen and diesel prices based on a common underlying crude oil price for each pair.

Table 4: Predicted undiscounted cost ratios of sample low-volume bitumen surfaced road (from Table 3) for selected diesel and bitumen prices

Estimated Total oil-price linked costs associated with construction and maintenance of a bitumen road over 10 years (R)							
construction start da	diesel price	diesel costs (base on site)	(incl construction of base)	bitumen price (/	bitumen cost	TOTAL diesel & bitumen (base on site)	bitumen (incl construction of base)
1/31/2003	3.648	10945.824	101352.384	1875	22500	33445.82	123852.38
2/28/2003	3.648	10945.824	101352.384	2015	24180	35125.82	125532.38
3/31/2003	3.808	11425.904	105797.664	2092.5	25110	36535.90	130907.66
4/30/2003	4.008	12026.004	111354.264	2025	24300	36326.00	135654.26
5/31/2003	3.538	10615.769	98296.254	1747.5	20970	31585.77	119266.25
6/30/2003	3.098	9295.549	86071.734	1690	20280	29575.55	106351.73
7/31/2003	3.238	9715.619	89961.354	1727.5	20730	30445.62	110691.35
8/31/2003	3.298	9895.649	91628.334	1812.5	21750	31645.65	113378.33
9/30/2003	3.308	9925.654	91906.164	1752.5	21030	30955.65	112936.16
10/31/2003	3.288	9865.644	91350.504	1702.5	20430	30295.64	111780.50
11/30/2003	3.364	10093.682	93462.012	1702.5	20430	30523.68	113892.01
12/31/2003	3.4137	10242.80685	94842.8271	1637.5	19650	29892.81	114492.83
1/31/2004	3.354	10063.677	93184.182	1650	19800	29863.68	112984.18
2/29/2004	3.564	10693.782	99018.612	1712	20544	31237.78	119562.61
3/31/2004	3.564	10693.782	99018.612	1702	20424	31117.78	119442.61
4/30/2004	3.701	11104.8505	102824.883	1672	20064	31168.85	122888.88
5/31/2004	3.751	11254.8755	104214.033	1672	20064	31318.88	124278.03
6/30/2004	4.051	12155.0255	112548.933	1860	22320	34475.03	134868.93
7/31/2004	3.891	11674.9455	108103.653	1820	21840	33514.95	129943.65
8/31/2004	3.761	11284.8805	104491.863	1756	21072	32356.88	125563.86
9/30/2004	4.141	12425.0705	115049.403	1834	22008	34433.07	137057.40
10/31/2004	4.381	13145.1905	121717.323	1461.373	17536.476	30681.67	139253.80
11/30/2004	4.601	13805.3005	127829.583	1900	22800	36605.30	150629.58
12/31/2004	4.374	13124.187	121522.842	1816	21792	34916.19	143314.84
1/31/2005	3.984	11953.992	110687.472	1650	19800	31753.99	130487.47
2/28/2005	3.914	11743.957	108742.662	1721	20652	32395.96	129394.66
3/31/2005	4.274	12824.137	118744.542	1791	21492	34316.14	140236.54
4/30/2005	4.928	14786.464	136914.624	1927	23124	37910.46	160038.62
5/31/2005	5.058	15176.529	140526.414	2112	25344	40520.53	165870.41
6/30/2005	4.888	14666.444	135803.304	2132	25584	40250.44	161387.30
7/31/2005	5.398	16196.699	149972.634	2260	27120	43316.70	177092.63
8/31/2005	5.568	16706.784	154695.744	2294	27528	44234.78	182223.74
9/30/2005	5.538	16616.769	153862.254	2320	27840	44456.77	181702.25
10/31/2005	5.598	16796.799	155529.234	2533	30396	47192.80	185925.23
11/30/2005	5.598	16796.799	155529.234	2575	30900	47696.80	186429.23
12/31/2005	5.298	15896.649	147194.334	2621	31452	47348.65	178646.33
1/31/2006	5.178	15536.589	143860.374	2461	29532	45068.59	173392.37
2/28/2006	5.178	15536.589	143860.374	2405	28860	44396.59	172720.37
3/31/2006	5.178	15536.589	143860.374	2475	29700	45236.59	173560.37
4/30/2006	5.441	16325.7205	151167.303	2539	30468	46793.72	181635.30
5/31/2006	5.711	17135.8555	158668.713	2579	30948	48083.86	189616.71
6/30/2006	6.001	18006.0005	166725.783	2676	32112	50118.00	198837.78
7/31/2006	6.321	18966.1605	175616.343	2728	32736	51702.16	208352.34
8/31/2006	6.541	19626.2705	181728.603	2896	34752	54378.27	216480.60
9/30/2006	6.291	18876.1455	174782.853	3010	36120	54996.15	210902.85
10/31/2006	5.951	17855.9755	165336.633	2800	33600	51455.98	198936.63
11/30/2006	5.931	17795.9655	164780.973	2800	33600	51395.97	198380.97
12/31/2006	5.681	17045.8405	157835.223	2665	31980	49025.84	189815.22
1/31/2007	5.511	16535.7555	153112.113	2831	33972	50507.76	187084.11
2/28/2007	5.421	16265.7105	150611.643	2821	33852	50117.71	184463.64
3/31/2007	5.521	16565.7605	153389.943	2722	32664	49229.76	186053.94
4/30/2007	5.901	17705.9505	163947.483	2808	33696	51401.95	197643.48
5/31/2007	6.201	18606.1005	172282.383	2950	35400	54006.10	207682.38
6/30/2007	6.273	18822.1365	174282.759	2956	35472	54294.14	209754.76
7/31/2007	6.363	19092.1815	176783.229	3006	36072	55164.18	212855.23

Table 5 provides parameters for a gravel road of comparable dimensions.

Table 5: Sample parameters for a gravel road

1km GRAVEL low volume road

gravel input (m³):	**450**	**Construction / Maintenance:**	
length (m)	**1000**	reshaping (#times/yr)	**3**
width (m)	**6**	# times regravelled in 10 yrs	**3**
thickness (m)	**0.075**		

Haulage (/km hauled)

diesel (litres /m³/km)	volume hauled (m³)	**diesel consumption (l)**
0.44	**450**	**198**

Construction & maintenance

	# times in 10 year period	diesel (litres per/m³/km)	**diesel consumption (l)**	*Notes*
rolling	4	2	**8**	*4 passes at 0,5l per pass on a kilometre road*
watering	4	1	**4**	*2 passes at 0,5l per pass on a kilometre road*
reshaping	30	2.5	**75**	*5 passes at 0,5l per pass on a kilometre road*
				diesel consumption for transport of grader, water truck and roller to the road sit is not included

Overall Diesel consumption (l)

rolling & watering (at construction and regravelling)	12
haulage (at construction and regravelling)	79200
re-shaping (routine)	75
TOTAL	79287

Distance hauled (km):	**100**

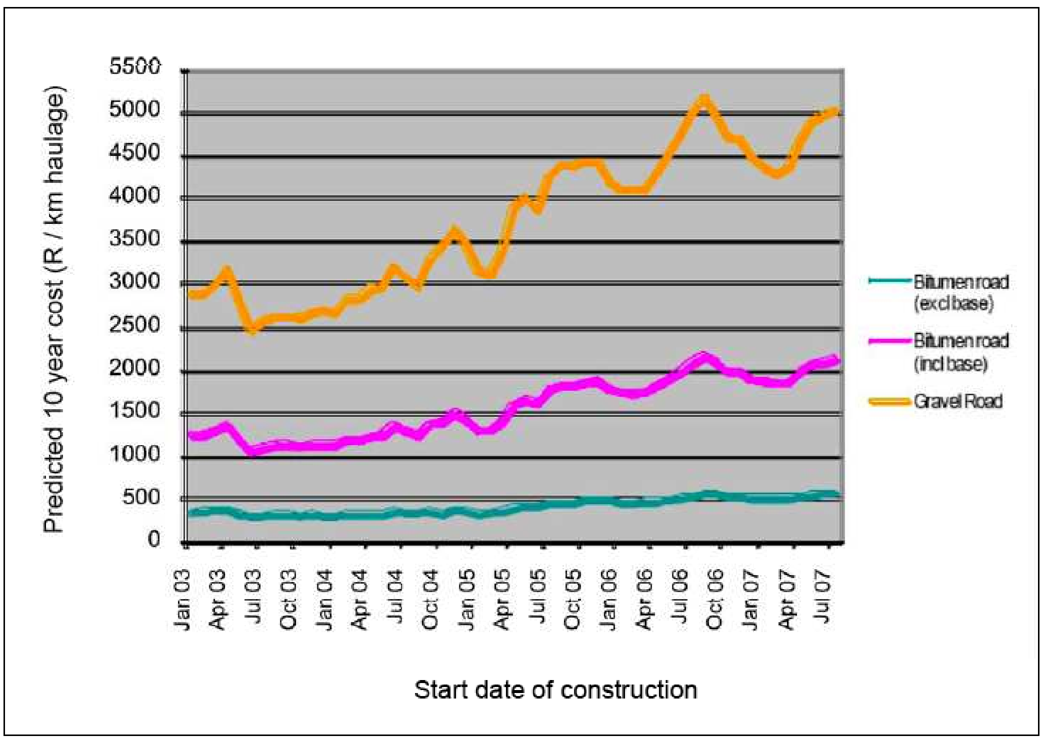
Based on these parameters, Table 6 shows impacts on road construction and undiscounted maintenance cost ratios for selected diesel prices.

Table 6: Predicted undiscounted cost ratios of sample gravel road (from Table 5) for selected diesel prices

Estimated Total Diesel costs associated with construction and maintenance of a 1km gravel road over 10 years (R)		
construction start date	diesel price	diesel costs
1/31/2003	3.648	289238.98
2/28/2003	3.648	289238.98
3/31/2003	3.808	301924.90
4/30/2003	4.008	317782.30
5/31/2003	3.538	280517.41
6/30/2003	3.098	245631.13
7/31/2003	3.238	256731.31
8/31/2003	3.298	261488.53
9/30/2003	3.308	262281.40
10/31/2003	3.288	260695.66
11/30/2003	3.364	266721.47
12/31/2003	3.4137	270662.03
1/31/2004	3.354	265928.60
2/29/2004	3.564	282578.87
3/31/2004	3.564	282578.87
4/30/2004	3.701	293441.19
5/31/2004	3.751	297405.54
6/30/2004	4.051	321191.64
7/31/2004	3.891	308505.72
8/31/2004	3.761	298198.41
9/30/2004	4.141	328327.47
10/31/2004	4.381	347356.35
11/30/2004	4.601	364799.49
12/31/2004	4.374	346801.34
1/31/2005	3.984	315879.41
2/28/2005	3.914	310329.32
3/31/2005	4.274	338872.64
4/30/2005	4.928	390726.34
5/31/2005	5.058	401033.65
6/30/2005	4.888	387554.86
7/31/2005	5.398	427991.23
8/31/2005	5.568	441470.02
9/30/2005	5.538	439091.41
10/31/2005	5.598	443848.63
11/30/2005	5.598	443848.63
12/31/2005	5.298	420062.53
1/31/2006	5.178	410548.09
2/28/2006	5.178	410548.09
3/31/2006	5.178	410548.09
4/30/2006	5.441	431400.57
5/31/2006	5.711	452808.06
6/30/2006	6.001	475801.29
7/31/2006	6.321	501173.13
8/31/2006	6.541	518616.27
9/30/2006	6.291	498794.52
10/31/2006	5.951	471836.94
11/30/2006	5.931	470251.20
12/31/2006	5.681	450429.45
1/31/2007	5.511	436950.66
2/28/2007	5.421	429814.83
3/31/2007	5.521	437743.53
4/30/2007	5.901	467872.59
5/31/2007	6.201	491658.69
6/30/2007	6.273	497367.35
7/31/2007	6.363	504503.18

Using the above model for generating simulations, Figure 7 compares undiscounted cost ratios per km of haulage distance between a gravel source and a construction or maintenance point over a 10-year period for three road types, given ratios between real oil prices as they varied between January 2003 and July 2007. The green curve shows bitumen and diesel cost predictions for a bitumen surface using an existing base and on-site aggregate and/or sand. The pink curve shows cost predictions for the same road when aggregate must be hauled to the road site and spread over the road surface before bitumen surfacing. The orange curve shows cost predictions for an unsealed gravel road maintained as per the optimal schedule assumed in Tables 5 and 6. Figure 7 illustrates clearly that, when gravel road construction and maintenance are compared with the construction and maintenance of a bitumen surfaced road, the diesel cost component of the total undiscounted cost of an unsurfaced road outweighs the combined undiscounted bitumen and diesel costs associated with constructing and maintaining a low-volume bitumen-sealed, or even a full (i.e., standard Hot Mix Asphalt paved) bitumen road. The comparison will of course be still more favourable for sealing an already constructed gravel road.

Figure 7: Petroleum price impacts on maintenance costs per km of haulage for three different types of road



The modelling above suffices to show that as the price of oil rises, undiscounted opportunity cost ratios between unsurfaced and surfaced roads must shift in the direction of surfaced roads.

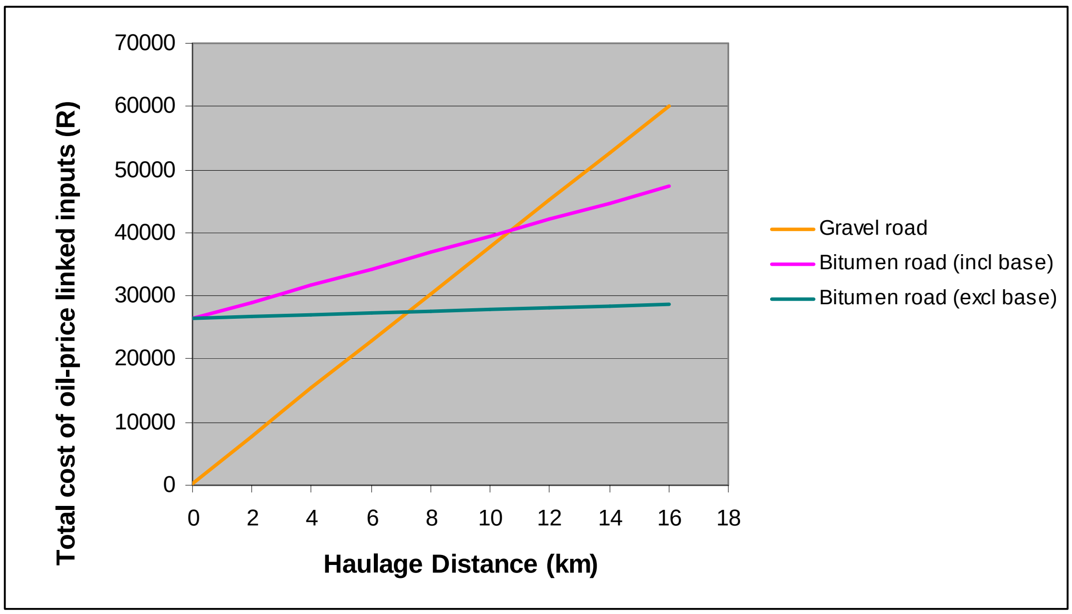
We complete the exercise by displaying, in Table 7, real values of the above ratios as at July 2007 for plausible haulage distances in SA, calculated over a 20-year period.

Table 7: Sensitivity to variations in haulage distances of oil-linked components of undiscounted construction and maintenance costs for three types of roads

				Bitumen oil-price linked costs							
	Gravel diesel costs			Including construction of base				Excluding construction of base			
Haulage distance (km)	Construc-tion & main-tenance	Haulage	Gravel road total (R)	Construc-tion (diesel)	Haulage (diesel)	Bitumen input (R)	Bitumen road total (incl base) (R)	Construc-tion (diesel)	Haulage (diesel)	Bitumen Input (R)	Bitumen road total (excl base) (R)
0	87	0	408.9	3	0	26400	26414.1	0.5	0	26400	26402.35
2	87	1584	7853.7	3	555.6	26400	29025.42	0.5	60	26400	26684.35
4	87	3168	15298.5	3	1111.2	26400	31636.74	0.5	120	26400	26966.35
6	87	4752	22743.3	3	1666.8	26400	34248.06	0.5	180	26400	27248.35
8	87	6336	30188.1	3	2222.4	26400	36859.38	0.5	240	26400	27530.35
10	87	7920	37632.9	3	2778.0	26400	39470.70	0.5	300	26400	27812.35
12	87	9504	45077.7	3	3333.6	26400	42082.02	0.5	360	26400	28094.35
14	87	11088	52522.5	3	3889.2	26400	44693.34	0.5	420	26400	28376.35
16	87	12672	59967.3	3	4444.8	26400	47304.66	0.5	480	26400	28658.35

Table 7 is displayed graphically in Figure 8.

Figure 8: Graph of Table 7



In application, ‘haulage distance’ on a road should be understood as the average viable transport distance between each point on the road and the nearest source of adequate aggregate material.

It will be seen that building and maintaining a bitumen road without aggregate consumes fewer oil-based inputs over 20 years than building and constructing an unsurfaced road, measured by Rand cost, at an average haulage distance of just over 7 km. Sealing an aggregate road consumes fewer oil-based inputs, measured by Rand cost, at an average haulage distance of 11 km. This corresponds to findings from South-East Asia as reported in Jahren *et al* (2005). Given that the oil-based cost of bitumen is included in this model, it illustrates the extent to which bitumen, despite being a petroleum-derived product, does not represent an intensive allocation of this ever-costlier commodity to roads relative to its main alternative.

We have not been able to obtain reliable information on the average distance between each point on the South African non-national road network and the nearest adequate source of gravel. It appears that obtaining this knowledge would require commissioning a new aerial survey on a national scale. We therefore resort to the highly inexact procedure of guessing a South African figure by reference to that for Namibia, which was determined in 1992 to have then been 10 km (Dierks 1992). Namibia is of course more sparsely settled and developed than South Africa. On the other hand, SA's municipalities make up such a tiny *spatial* proportion of the country that their influence on the denominator of the relevant ratio can be ignored (though their influence on the numerator will be considerable). Furthermore, our main interest here is in distances between gravel sources and points on *rural* roads, since the overwhelming majority of kilometres of unsurfaced roads are outside metropoles and large towns. Thus the average *relevant* haulage distances for Namibia and South Africa may not be dramatically far apart. Three experienced South Africa pavement engineers whom we consulted told us that they consider our suggestion of 7 km to be reasonable for SA.

We now draw a provisional conclusion prior to consideration of discounting. To the extent that SA wishes to minimize oil consumption by its expanded road works programme, in part to minimize the distortionary effect of rising import prices on its economy, application of the model discussed in this section implies that either new borrow pits should be dug so as to match oil-price increases with reduced haulage distances, *or*:

> (*) at present oil prices – but given expectations of rising oil prices – any gravel road that averages more than 10 km in haulage distance from nearest sources of adequate aggregate material should either be allowed to deteriorate and then be abandoned or, if it is deemed to be worth maintaining, sealed with a bitumen surface at its soonest scheduled maintenance point.

In Section (5) we will indicate why haulage distances are presently increasing in SA and are overwhelmingly likely to continue to do so. Thus the second disjunct (*) of the disjunctive conclusion above simply becomes our conclusion in itself.

Note that this applies given present oil prices plus the mere expectation of undetermined but higher oil prices in future. As the actual oil price rises, the specific oil-minimising average haulage distance cited above will drop. We have not tried to calculate an oil price at which (in the absence of discounting) all gravel roads should be sealed. There are two reasons for this. First, the other costs in our model are entangled with the oil price, in two ways: (i) oil is an input to the manufacture, purchase, servicing and operation of machinery and to the extraction of aggregate material, and (ii) in SA, rising oil prices cause currency depreciation, which increases the cost of imported machinery. Thus the 'no gravel' oil price threshold can only be determined by application of a general equilibrium model of the South African economy. We have insufficient confidence in the capacity of any existing such model to make so fine-grained a prediction. Second, going to all this trouble to determine a 'no gravel' oil price that is independent of discounting would involve moving a large mountain to bring forth a very small mouse. Discount rates are crucially sensitive to uncertainty with respect not only to expected future price levels, but also to the rate at which those levels change.

Instead of trying to generate an overly precise number that would be of dubious economic validity, we instead reason as follows. We have shown in this section that as the oil price rises we approach a 'no gravel' threshold at an accelerating pace *unless* assets used to build and maintain roads have high present opportunity costs relative to future ones, thus implying a high discount rate on resources invested in roads. The higher the discount rate, the greater the extent to which present construction costs, which favour gravel roads, dominate maintenance costs, which favour surfaced roads. (Thus, for example, Jahren *et al* [2005] conclude that in Minnesota most gravel roads should be left as gravel unless shadow benefits from greater driver safety on pavement are set much higher than market values of life and limb as indicated by US insurance prices.) We will therefore now defend a conservative estimate of the time point at which investment in a low-volume surface seal pays for itself given discounting at the standard National Accounting benchmark used by Treasury. Then we will have two independent conservative numbers: (1) the oil-use minimizing average haulage distance threshold given present oil prices, and (2) the maximum period of time after which an unsurfaced road investment that has worthwhile opportunity cost begins delivering reduced relative opportunity costs if it is sealed. (1) tells us that we should seal roads at an accelerating rate as oil prices rise unless (2) moves in the opposite direction. But (2) will have been arrived at independently of consideration of shadow prices. In Section 5 we will consider relevant shadow-priced factors in surface choice, and suggest on this basis that (2) is a limiting point; any plausible value of the real opportunity cost of maintaining a gravel road as gravel (let alone building a new unsurfaced road) must be higher than (2). It will then follow as a general conclusion that as oil prices rise we should seal increasingly higher proportions of roads.

4. Discounting and the minimum break-even point on low-volume bitumen surfaces

Since, by the logic of our argument explained above, we aim in this section at a conservative estimate, we base our analysis on cost data from the City of Tshwane (Henning 2007). In consequence of the urban environment, abundance of borrow pits, and concentration of traffic volumes within the higher end of the low-volume range (which pushes up maintenance costs on bituminous surfaces), use of these data, rather than data from rural jurisdictions, biases the comparisons in favour of unsurfaced roads.

An optimally maintained bitumen-surfaced low volume road is resurfaced every eight to ten years and needs minimal maintenance in the interim periods. An optimally maintained gravel road, on the other hand, is reshaped two to four times annually and completely re-gravelled every two years. In consequence, the maintenance bill for Tshwane's small extent of gravel roads stands at approximately R35 100 / km per annum, while low-volume surfaced roads require R23 220 / km per annum (Henning, 2007). Thus unless discount rates erode present value at a rate equal to or faster than the accumulation of maintenance-cost margins, there must be a point in time following surface sealing at which the initial investment is recouped. We refer to this as the break-even point. In this section, we estimate this point using the Tshwane data, taking into account only market costs and benefits (i.e., prior to consideration of shadow costs and benefits).

Table 8 shows the data inputs used to compare the NPV of the stream of costs associated with Tshwane's gravel roads in comparison to low-volume bitumen surfaced roads. We compare two 1 km, 6m-wide roads. Each road's NPV is given by the standard formula

$$NPV = \sum_{t=1}^{n} (\frac{C_t}{1+r^t} - (C_0 + \kappa(\sum_{t=1}^{n} C_1 + C_2 +,...,+ C_n)$$

where t = the time of valuation, n = years over which benefits and costs are to be estimated, r = the discount rate, C_t = the net balance at t, C_0 = the total initial investment, C_n = investment (i.e., maintenance costs) in year n and κ = average CPIX in years 1, … n.

The break-even point is found by equalising the NPVs and solving for n. The National Treasury's working rate of 9% is used as the discount rate, and construction costs are expected to inflate at 6%, the upper bound of the SA Reserve Bank's inflation target (which, as of present writing, CPIX exceeds by 1.3%). The base cost of annual maintenance assumes blading of the gravel surface twice annually, although the optimum would be up to four times annually. (Again, we make conservative assumptions that stack the deck in favour of finding gravel comparatively efficient.) The crucial parameter is the maintenance PV of 2.83%, which sets off the increasing maintenance cost against the Treasury discount rate. The initial surfacing cost of the bitumen road includes material and application, drainage mechanisms and a natural gravel base.

Table 8: Parameters for comparing discounted costs for unsurfaced and surfaced low-volume roads in Tshwane, 2007.

GRAVEL

DATA INPUTS

Initial gravelling costs	70800
Base cost of regravelling	91800
Discount rate	0.09
Inflation of construction costs	0.09
Base cost of annual maintenance	35100
Frequency of regravelling	Every 2.5 years
Effective discount rate	0.02830189

20 year outlay

Initial gravelling	70800
Regravelling PV	543388.9
Maintenance PV	530493
TOTAL PV	**1144682**

BITUMEN

DATA INPUTS

Initial surfacing cost	245400
Discount rate	0.09
Inflation of construction costs	0.09
Base cost of annual maintenance	23220
Frequency of resurfacing	Every 2.5 years
Effective discount rate	0.02830189

20 year outlay

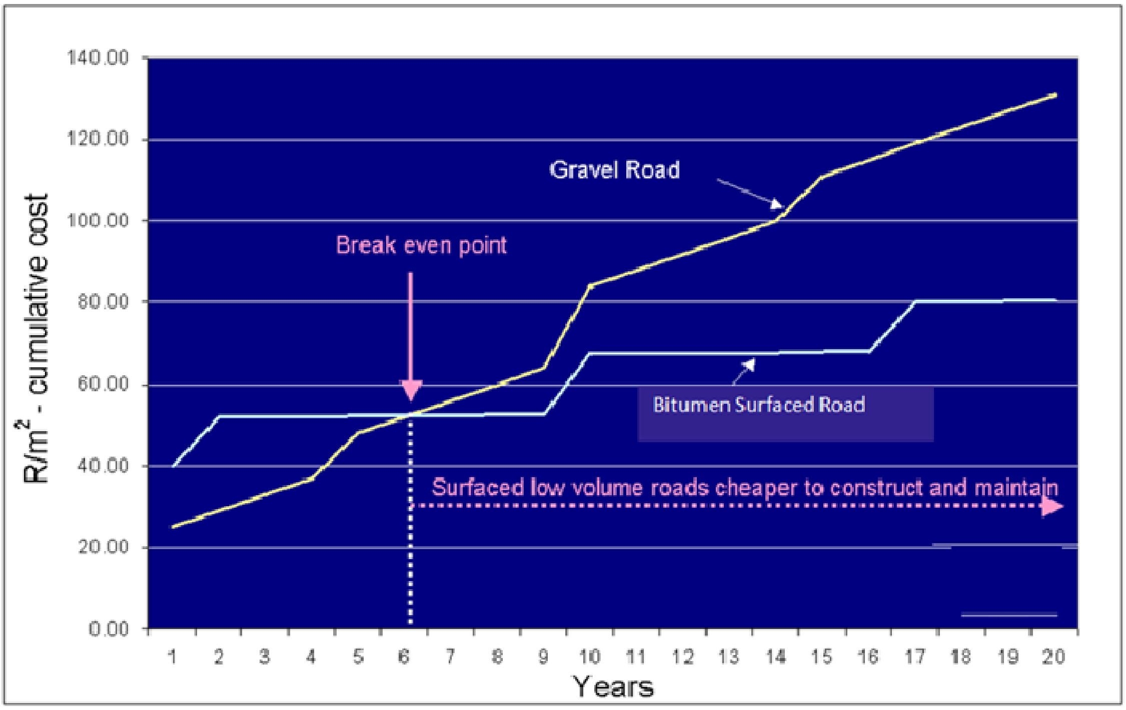
Initial surfacing	245400
Resurfacing PV	339384.5
Maintenance PV	350941.5
TOTAL PV	**935726.1**

Data Source: Henning, 2007 and Naidoo, Purchase and Distin, 2004

Using these data, the NPVs of the two 1 km stretches of road are equal at 5.6 years.

Henning (2007) reached a similar conclusion from analysis of the Tshwane data, identifying the break-even point at just over 6 years, though he does not reproduce the model he used. We reproduce his findings in Figure 9.

Figure 9: Henning's (2007) break-even point for a low-volume surfaced road relative to an equivalent unsurfaced aggregate road, City of Tshwane 2007



Source: Henning, 2007

An estimate in the regions of ours and Henning's represents, as we indicated, an upper bound for break-even points in SA. There are very few unsurfaced roads in the metropoles. For the overwhelming majority of the rural unsurfaced roads, haulage costs of gravel will be higher than in Tshwane, and bitumen surfaces will require less frequent maintenance because of lower traffic volumes.

Note that at no point in the reasoning above do we assume that the NPV of either type of road is positive. Thus it does not follow that if we surface every gravel road in SA (and inflation is held on average within target) we will have recouped the opportunity cost of the public investment after a maximum of 5.6 years. Rather, our argument indicates that *if* an unsurfaced road is worth maintaining, at a rate such that deterioration does not outpace repair rate and erode its value, *then* if it is sealed the investment should be expected to pay positive returns in saved opportunity costs after a maximum of 5.6 years. This conclusion requires some obvious warnings and qualifications. The future is always to some extent uncertain. A road that is worth maintaining in year 1 may no longer be worth maintaining in year *n* if patterns of use change, or a more pressing demand for public funds evolves elsewhere in the economy. However, these considerations apply to any commitment to a maintenance programme. Again, our analysis says nothing about when it is rational to invest in a road in the first place; it does, however, strongly suggest that when we independently consider a road a sound site of investment, it should be sealed.

We have produced two independent conclusions prior to any consideration of shadow prices. We now combine them. As the price of oil rises we should seal higher proportions of gravel roads unless (i) average haulage distances are reduced to compensate, (ii) national accounting discount rates increase, or (iii) inflation rises well beyond the upper bound of the Reserve Bank target. We will now argue that (i) is highly unlikely, and its opposite highly likely, due to shadow costs associated with use of gravel.

5. Shadow costs of unsurfaced roads

Gravel roads impose a range of negative externalities on both drivers and the community at large. A true estimation of the opportunity cost of constructing a gravel road, and of maintaining such a road as gravel rather than re-sealing it, would incorporate shadow prices for these externalities. If unsurfaced roads carry a range of shadow costs that bitumen-surfaced low-volume roads avoid, then this must affect the break-even point in time: for a given rate of inflation it must grow shorter. Because the negative externalities also reduce the supply of gravel, and hence increase haulage distances, they also reduce the threshold for gravel use at which expenditure on oil is minimised.

Clearly, it would be best to explicitly estimate these values. Unfortunately, accurate shadow pricing of most of the externalities associated with unsurfaced roads is extremely informationally demanding. Surveys are unreliable at yielding shadow prices if respondents have no monetary incentive to answer accurately. The problem here is not mainly that people misrepresent their willingness to pay to avoid negative externalities – though a newly paved road in a community does represent, to at least some extent, a wealth transfer to that community from national or provincial resources, so people *do* have reason to exaggerate the impact of externalities they experience if this exaggeration has no cost for them. But the main problem is that people are simply not practiced at, and not good at, assigning monetary values to non-traded goods and bads. In our view, the only truly reliable methods for measuring shadow costs of factors such as environmental degradation from dust, convenience value of faster commuting, and minimization of ugly borrow pits in landscapes, is to conduct an ecological or laboratory experiment that allows people to trade these costs and benefits for money. An example of an ecological experiment to elicit the shadow price of commuting time is to establish a toll road while leaving an equivalent road between the same points un-tolled, and then to examine effects of various price levels on people's switching behaviour between the two roads. This is an absurdly expensive procedure except under special, fortuitous circumstances that happen to arise on their own. Laboratory experiments with representative subjects – exercises in so-called 'behavioural economics' – are an excellent alternative method for estimating shadow prices. However, it is often impractically time-consuming and costly to run experiments with large enough samples to gain representativeness when one is interested in large-scale public goods such as roads, especially as subjects must be paid enough to induce choices that accurately predict their behaviour 'in the wild'.

We therefore do not attempt any quantitative estimation of shadow prices. The best we can do is describe negative externalities associated with gravel roads, noting, again, that each must to some unknown extent shift our two conservative numbers in the direction of implying the sealing of a higher proportion of SA's roads.

Negative externality #1: health and environment impacts. Each year, more than 30 million cubic metres of gravel blows or washes off SA's roads and must be replaced (NDoT 2002). Because of this dust they spread onto crops, wildlife and people, gravel roads impose heavier environmental costs than surfaced ones. Dust causes allergies and respiratory illness, especially in small children. People must clean their homes, businesses and vehicles more often in dusty conditions, which must reduce either their leisure time or their productivity. This cost may appear insignificant to a particular person, but seemingly trivial expenses can produce high overall costs when multiplied by enough person hours. In addition, borrow pits are generally regarded as insults to natural landscapes, both aesthetically and because they impact vegetation through disruption to water tables and absorption patterns.

Negative externality #2: impacts on vehicle operating costs. Rougher road surfaces increase vehicle operating costs, especially petrol use and tyre wear. Petrol use premiums on gravel roads are especially noteworthy if one of the considerations leading to concern about bitumen use is its upward influence on national consumption of petroleum products. Netterberg and Pinard (1991) estimate that equivalent traffic volumes burn, on average, 6% to 7% more fuel on gravel roads than on paved ones. Dierks (1992) suggests a substantially higher figure of 20%, partly reflecting a restriction to lower quality gravel roads in his sample. Using South African data, Dierks summarizes overall extra vehicle operating cost differences on medium-grade gravel roads (IRI = 8) as compared to medium-grade paved roads (IRI = 4) at a low end of 19% for buses and 27.5% for medium-weight trucks. His overall conclusion, based on a mix of Namibian and South African data, is that merely factoring vehicle operating costs into the comparative economic evaluation of road types reduces the regional threshold AADT for resurfacing a gravel road with a single surface dressing to 120, and to 160 for double surface dressing. (This compares with the standard regional threshold of 200 cited in Section 2. Dierks argues that this remains the correct threshold, under his calculations, for constructing a full Hot Mix Asphalt road.) If the threshold of 120 were adopted in Gauteng, this would result in 50% of present gravel road kilometres being regarded as warranting upgrade. Note that this recommendation is based on consideration of negative externality #2 *by itself*.

Negative externality #3: safety. Surfaced roads are safer than gravel roads because on paved surfaces vehicles can brake to faster stops from equivalent speeds and are less disposed to skid. According to Caterpillar Inc. (2004), the coefficient of traction for rubber tyres on a paved road is 0.90, as opposed to 0.36 on unsealed gravel. This is offset somewhat by the fact that vehicles tend to travel faster on surfaced roads. However, accident data save us from having to speculate about the relative strengths of these countervailing influences. Labuschagne and Schermers (1998) conclude that road surface conditions contribute to about 8.6% of all accidents in SA, and that surface improvements would prevent 10% of these altogether – so, 0.86% of the total. The accident rate per million vehicle kilometres on gravel roads is more than double that for two-lane paved roads, and the composition of fatalities among accidents on gravel (10.9%) is *higher* than on 2-lane paved roads (7.8%), and much higher than on full-speed freeways (3.2%). Thus effects of differences in vehicle control appear to swamp differences in driving speed where accident harm is concerned.

Externalities 2 and 3 above influence surfacing choice in SA through their inclusion in, and feedback-linked relationships with other elements of, the set of performance indicators adopted by the Department of Transport (Table 2). Externality 1 is currently having by far the largest impact. NDoT (2002) acknowledges a growing need to quarry large volumes of gravel from pits that are unevenly spread over the country, thus converging 'from below' with the pressure of the oil price 'from above' toward the oil-use minimising haulage distance threshold modelled in Section 3. According to The Mineral and Petroleum Resources Development Act (Act 28 of 2002), any level of government must submit an environmental management programme for approval whenever it intends to open new quarry facilities. Environmental Impact Assessments (EIA) must be submitted, along with proposed sustainable environmental management programmes, to the Department of Minerals and Energy. SANRAL has recently experienced setbacks and added costs associated with the timely approval of EIAs and mining permits for the establishment of new quarries and borrow pits (National Treasury 2006). Despite efforts to streamline the EIA approval process, particularly with respect to infrastructure projects, the EIA procedure is a complicated one, typically involving the formation of a Management Programme which covers practices for soil handling, land formation, erosion, surface drainage and pollution control. In addition, specific to each potential quarry site, plans with respect to the preservation of natural vegetation and the demolition or optimal utilisation of existing man-made surface structures must be developed and implemented (CES 2005). Environmental concerns that effectively reduce the supply of gravel at a given price must have the effect of shortening the break-even figure estimated in Section 4.

Thus negative externalities associated with gravel roads influence both of our conservative numbers in the direction of implying higher proportions of sealed roads. Though we cannot quantify them, their relative magnitude appears to be very substantial. As indicated, externality 2 alone might justify sealing half of the unsurfaced roads in Gauteng. And externality 1 is probably the main driver of the collapsing supply of gravel in SA as depicted in Figure 6. We think it entirely plausible that if the negative externalities could be quantified and then applied to the haulage distance threshold and the break-even time point, we would discover that in SA it is *already* the case that if *any* road is worth maintaining it is worth sealing. This is *before* we consider a final, and highly significant, factor in optimising road surface choice: the opportunity cost of labour.

6. Labour-intensive road maintenance and shadow wages

Gravel roads, due to their dependence on long-distance haulage of heavy material and reliance on large machines for grading and smoothing, cannot be constructed and maintained mainly or entirely using small equipment that can be operated by unskilled people. Bituminous surfaces on the other hand, can be constructed and maintained with light equipment that requires little training to master (Pinard and Overby 2006). To convey some sense of the comparative magnitudes by reference to a small-scale example, a project which used manually operated chip spreaders to construct low-volume sealed roads near Siyabuswa in Mpumalanga was documented in early 2005. The project resulted in the employment of more than 60 mainly unskilled workers for a month, whereas the alternative capital-intensive methods that would have been required for an unsurfaced road adequate to the relevant AADT level would have employed 5 to 6 people for a few days. A major advantage for small, emerging contractors was the reduced capital investment made possible by the manual chip spreaders and surfacing handsprayers as alternatives to more expensive heavy chip spreading equipment (Pagel, Distin and Stonemann 2005).

Projects to construct and maintain gravel roads thus fail to take account of SA's abundance of underutilised labour and are less effective at developing human capital in small contractors than projects to construct and maintain sealed surfaced roads. National Government's Extended Public Works Programme (EPWP) mandates that wherever labour-intensive methods can be deployed for the same budget outlay as capital-intensive methods, the former should be favoured. In fact this is too conservative, using an accounting measure of value where an economic measure would be more appropriate. Use of small contractors in road construction and maintenance builds human capital in the form of management, tendering and investment skills and facility with hand-held bitumen spreaders. Since such capital is an economic asset with future multipliers, we should not implicitly set our willingness to invest in it at zero, as the EPWP presently does. Furthermore, SA's labour market is characterized by an extreme case of what economists call 'modern sector dualism', that is, a large wage gap between formal-sector employment and informal-sector employment outside of subsistence agriculture. (In most African countries, underemployed people mainly work at household farming. In SA, underemployed people in the countryside are much more likely to subsist crucially on income from social grants.) For reasons to be explained later, this feature of the economy has the effect of reducing the shadow wage rate of underemployed labour, especially in rural communities. If such labour can be invested in construction and maintenance of surfaced roads to a significantly greater extent than in maintenance of gravel roads, this implies a further reduction in the time span from any given surfacing decision to the break-even point.

The Expanded Public Works Programme (EPWP) reflects the South African Government's aim to harvest more of the value of under-utilised labour, both to improve the overall productivity of the economy and to raise the quality of life of presently under-employed people and their dependents. EPWP initiatives use public sector expenditure by extending the labour aspect of state projects. Expanded work opportunities have been identified within infrastructure projects, social service sectors and environmental projects. The medium term aim of the EPWP is to create work opportunities for a minimum of one million people between 2004 and 2009.

The economic basis of the EPWP as it is currently formulated is open to criticism. In mandating that labour-intensive production methods should be used wherever they have an accounting cost no higher than alternative capital-intensive methods, the EPWP ignores (i) the possibility of building the national asset stock by investing in human capital and (ii) the difference between market wages and shadow wages. We will explain each of these problems in turn. Acknowledgement of the validity of these criticisms would imply expansion of the EPWP to include publicly funded subsidies for employers of labour-intensive methods, because the criticisms imply existence of public goods that without subsidies will be undersupplied in equilibrium.

Popular discussion of the EPWP tends to be confused by benchmarking targets of 'numbers of jobs' to be 'gained'. Unlike human capital, 'jobs' are not assets since they are functions of overall productivity in the economy and are not fixed in extent. A 'job' is best interpreted economically as a reduction in a job-holder's short-run insecurity with respect to expectations of income. This is of course of some value to the job-holder. But it should not be confused with income itself, which is far more important. Furthermore, providing greater security to a given worker has economic costs, which are typically borne by other workers elsewhere in the economy. It is usually impossible to determine where these costs lie. Thus, 'job creation' mainly has the effect of re-distributing welfare *among* the less well off, in an unintended and usually inefficient way.

On the other hand, if newly employed people learn skills from working – for example, in the case of road construction and maintenance, if groups of them develop capacities to manage projects as small contractors – then this increases the national human capital stock. We are not alleging here that the EPWP ignores training and skills development. For example, the Zibambele Road Maintenance Project (discussed further below) was initiated through a pilot system in which monthly tasks were set and monitored by overseers, each responsible for over 100 contracts. The overseers would then report to both social and technical consultants, who provided feedback intended to allow high-level tasks to be undertaken by locally recruited managers and workers in subsequent project stages. Instead, our point is that such human capital development improves not only the productivity of individual contracting firms, but potential national productivity. The private sector is not incentivized to fund this 'national premium'; therefore it should be funded by subsidies to labour-intensive production.

At least as important to our argument is the question of the shadow wage rate. We find it slightly scandalous that government has not thus far invested in the economic research necessary to rigorously estimate a set of shadow wage rates for the main sectors of the economy. This failure prevents us from being able to quantitatively estimate the impact of the shadow wage rate for low-skilled, underemployed South Africans on the relative opportunity costs of different types of roads. This is highly unfortunate, because the impact is probably considerable.

SA's labour market has two unusual features (aside from sheer wealth levels) among African economies, both of which should be expected to make the gap between formal-sector market wages and informal-sector shadow wages relatively extreme. First, due to the political strength of its labour unions, and consequent legal protection of workers' bargaining rights that are unique in Africa, the urban formal-sector wage rate is almost certainly well above the market-clearing rate. (The persistence of unemployment in cities is obvious evidence for this.) Second, subsistence agriculture is of little economic significance in SA due to the country's abundance of large efficient farms, in strong contrast to the regional norm. The shadow wage for a worker represents the cost to the economy of moving that person from his or her present occupation to employment paying the formal-sector market wage in exchange for productivity that is normative for that sector. In neighbouring countries, this cost is borne by other members of the worker's household, who may have to invest more hours of farming to sustain themselves. However, in SA many under-employed people contribute less to their households' productivity than they consume of their households' income. This is mainly because a disproportionate share of the household incomes of households with unemployed members are earned by older pensioners and people receiving disability grants (Bhorat *et al* 2001; FHISER 2006). If such people are transferred to production of infrastructure then

(i) if their labour is at least as productive as an alternative unit of capital that could have been invested instead, as envisaged for use of labour-intensive methods under the EPWG, their shadow wage is zero or negative;

(ii) if their productivity, in economic terms, is not zero, then their shadow wage is zero.

Slightly more technically, if we present the welfare of the public economy as follows:

$W = W(G1, G2, G3, \ldots Gn)$

where each project input is depicted as a government control variable G*i*, then the shadow price of any G*i* is $\delta W/\delta Gi$. Then the overall measure of marginal welfare is given by

$$dW = (\delta W/\delta G1)\, dG1 + (\delta W/\delta G2)\, dG2 + \ldots + (\delta W/\delta Gn)\, dGn.$$

If, for rural informal-sector labour (*rl*), $\delta W/\delta Grl = 0$, then if workers are drawn from *rl* to contribute to an infrastructure project that has positive value, the opportunity cost to overall welfare also equals zero. If $\delta W/\delta Grl < 0$ because those able and wanting to work are consuming resources at the expense of people unable to work, then wages paid to the former buy an opportunity gain to overall welfare that is *additional to* the value of the asset they construct or maintain (assuming the value of that asset is positive), plus the value of the income to the workers, plus the value of any new human capital that is created.

What about projects closer to urban areas, where, plausibly, some labour will be withdrawn from sectors of the economy where productivity is greater than zero? Here the absence of national research on shadow wage rates becomes a crippling obstacle. However, SA's relatively high urban unemployment rate is almost sure evidence that the shadow wage rate among unskilled adults able and wishing to work is lower than the legal minimum wage. Thus there must be *some* level of subsidisable labour-intensive public works just in case there is a means of ensuring that the projects in question draw some presently underemployed workers (as opposed to merely transferring workers from jobs they consider less desirable).

In all decisions on investment in infrastructure, it is preferable to invest in labour as a government control variable rather than in a risk-free asset up to the point where the difference between productivity per unit labour time multiplied by the market wage rate and productivity per unit labour time multiplied by the shadow wage rate is greater than the returns on the risk-free asset. Suppose, as the government clearly does, that investment in roads, including gravel roads, is economically sound.[7] Then it must follow from the fact that the shadow wage rate in rural SA is zero or negative, while machinery is less efficiently used in rural areas than in urban ones (due to transport costs and reduced economies of scale), that labour-intensive sealed surface construction is preferable to gravel road construction and maintenance even for a range of projects in which the accounting cost of the surfaced road is higher. Provision of some portion of this difference

[7] We infer this simply from the fact that the government *is* presently investing in gravel roads.

as a subsidy is then sound public economics. In urban areas our ignorance of relevant shadow wage rates blocks a similar inference.

It might be objected that, since SA is a heavily urban and (more to the point) rapidly urbanizing country, a programme of subsidies that focused on the rural population should be a low priority, even if it is demonstrably economically rational. We thus point out that there is controversy among development economists on the relationship between shadow wages and migration from rural to urban areas. (See Sah and Stiglitz 1985 for a review.) One of the factors that plausibly widens the apparent gap in SA between the legal minimum wage and the market-clearing urban wage is the fact that potential migrants are induced to 'race' one another for better-paying urban jobs; thus the supply of urban labour persistently outstrips the market's capacity to absorb it. If this is so, then programmes that improve the welfare of workers resident in rural areas may indirectly benefit workers living in cities, reducing the incentive of the former to join the race.

Examples of use of deliberately labour-intensive road construction and maintenance projects in SA are beginning to accumulate and to provide helpful data on the scale of potential benefits. In all cases these projects feature the construction of bitumen-sealed low volume roads, rather than unsurfaced ones.

The Zibambele Road Maintenance project was initiated in rural KwaZulu Natal in 1999, before the formalisation of the EPWP. Zibambele is Zulu for 'doing it for ourselves'. The project involves the use of labour intensive road maintenance methods contracted to more than 6000 rural households (KZN Provincial Planning and Development Commission 1999). A typical contract involves the household supplying a person to two weekdays worth of person hours working on the road, with the KZN Department of Transport ensuring the supply of a set of tools and basic training (Harvard Innovations, 2000).

The surfacing of gravel roads with graded crushed stone seals has created over 100 km of economically stimulating access roads in the eThekwini District Municipality (KZN's largest) since 1999 and has made use of labour-enhanced construction methods (Naidoo, Purchase and Distin 2004). Local contractors have observed that use of labour made good financial sense, particularly on areas of the road network where terrain and weather conditions limited the suitability of heavy construction machinery.

The Gundu Lashu Programme for Labour Intensive Rural Roads Maintenance is a current project in Limpopo province. Labour-based contractors have used low-volume sealed road construction techniques and this has resulted in both employment benefits for the area, as well as savings in construction costs and future maintenance bills (Paige-Green *et al* 2004). Part of the explicit motivation for this project was the growing local scarcity of good quality gravel to maintain the road network, which had been sharply driving up its cost.

In Section 5 we reviewed negative externalities associated with gravel roads and noted that their effect must be both to push the oil-use minimising haulage distance threshold toward the actual SA average haulage distance, and to reduce the period between a surfacing decision and the break-even point where investment in a bitumen surface is recouped. In the present section we have considered two major positive externalities from use of bitumen surfaces, if they are constructed and maintained using labour-intensive methods. These externalities are augmentation of the national human capital stock, and exploitation of differences between shadow wages and market wages (which is equivalent to putting otherwise wasted labour resources to productive use). These positive externalities have no impact on the price of gravel roads, but of course increase their opportunity cost if bitumen surfaces that can be constructed and maintained by unskilled people with light equipment are among the alternatives. On the other hand, by increasing the returns on a bitumen surfaced road, if that road is constructed and maintained using labour-intensive methods, the positive externalities must bring any given break-even point for the road in question closer to the present.

7. Conclusion / executive summary

The main conclusions of the foregoing report can be summarized as follows:

1. A substantially higher proportion of the price of gravel roads than of bitumen-surfaced roads is driven by the petroleum price. Therefore, as the petroleum price rises, the relative opportunity costs of gravel and surfaced roads should be expected to shift in favour of surfaced roads.

2. At present oil prices – but given expectations of rising oil prices – any gravel road that averages more than 10 km in haulage distance from nearest sources of adequate aggregate material should either be allowed to deteriorate and then be abandoned or, if it is deemed to be worth maintaining, sealed with a bitumen surface at its soonest scheduled maintenance point.

3. The specific figure cited in (2) will get smaller, at an accelerating rate, as the price of oil rises.

4. Barring a persistent surge in inflation beyond the official target of the Reserve Bank, an investment in a bitumen surface seal on any road that is worth maintaining at all for the sake of traffic volumes (see below) recoups its value in 5 to 6 years.

5. Significant but not quantified negative externalities associated with gravel roads make it likely that the supply of gravel will continue to contract, the oil-minimising haulage distance threshold for gravel roads will shrink (over and above shrinkage caused by rising oil prices), and the duration between a decision to surface and the break-even point will shorten.

6. Rural bitumen-surfaced roads that are constructed and maintained using labour-intensive methods bring two positive externalities: potential augmentation of human capital, and exploitation of SA's large gap between shadow wages of underemployed workers and formal-sector market wages. (This amounts to putting otherwise wasted resources to productive use.) This may directly benefit urban workers (over and above their share of the national benefit) if migration from the countryside is in part a race for scarce wage premiums. It is probable that labour-intensive road construction and maintenance in urban areas would also raise welfare by exploiting a gap between shadow wages and market wages, though we cannot be sure of this until shadow wages in different parts of the labour market

are quantitatively estimated. Government should therefore subsidise use of labour-intensive methods to construct and maintain bitumen-surfaced low-volume roads, at least in rural areas. Such subsidies should possibly also be offered in urban areas. The positive externalities associated with bitumen surfaced roads maintained by labour-intensive methods reduce the duration between the surfacing of such roads and the break-even point

We think it probable that, when all of the above conclusions are taken together, SA should maintain gravel roads only where AADT kevels are too low to normally justify expenditure on *any* road, but a community's access to a minimally acceptable quality of life is crucially dependent on it. (By 'minimally acceptable quality of life' we refer to whatever norm for this prevailing civic standards select.) We suspect that if maintenance of a low-volume road is justified by traffic volumes, then sealing of that road's surface with bitumen is also justified. In the absence of quantified shadow pricing of the negative externalities associated with gravel roads, and estimation of shadow wages in SA's labour markets, this must remain a conjecture. However, there are good reasons to believe that the unknown magnitudes are large. Given that our two estimated conservative numbers already suggest an aggressive surfacing policy for low-volume roads, we think our conjecture is very likely true. The end of the gravel road in SA may be at hand.

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