Using multi-source GPS data to characterise multi-day driving patterns and fuel use

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The use of global positioning system (GPS) technologies for collecting travel data is growing rapidly throughout the world. As GPS technologies improve, a number of shifts are occurring in their application. Data collection periods are also increasing beyond the traditional one-day survey, as respondents carry GPS devices for up to a week. This provides rich data on the day-to-day repetitiveness and variability of travel without adding to respondent burden.

The South African National Roads Agency Limited (SANRAL) has recently completed a major upgrade of 185 km of freeway infrastructure in Gauteng. The Gauteng Freeway Improvement Project (GFIP) was aimed at relieving congestion, improving traffic management through Intelligent Transport Systems deployment, and improving traffic safety on the province's extensive freeway network.

In a research project conducted to characterise multi-day driving patterns and fuel use, GPS data from commercial fleets was combined with project-specific, mobile GPS sources to analyse and compare private and commercial vehicle traffic in the same area. The purpose of the research project is to help improve the state of travel demand modelling in South Africa.

A three-day GPS survey of a sample of car drivers in Gauteng provided detailed information on the daily movements of these individuals. This information was used to extract the activity chain information needed for the simulation of travel plans using the Multi-agent Transport Simulation (MATSim) toolkit, which allows for large-scale transportation simulations. The same individuals will be resurveyed at one-year intervals to study long-term behaviour changes.

Obtaining GPS data

Data for commercial traffic was obtained from a commercial fleet management provider that continuously tracks the movements of 42 000 vehicles, while data for private car users was obtained from a panel of 720 drivers, whose multi-day driving activity was tracked using mobile passive GPS loggers. The study was therefore able to determine whether the subsample of drivers who are freeway users differed from the true population of freeway users in the area.

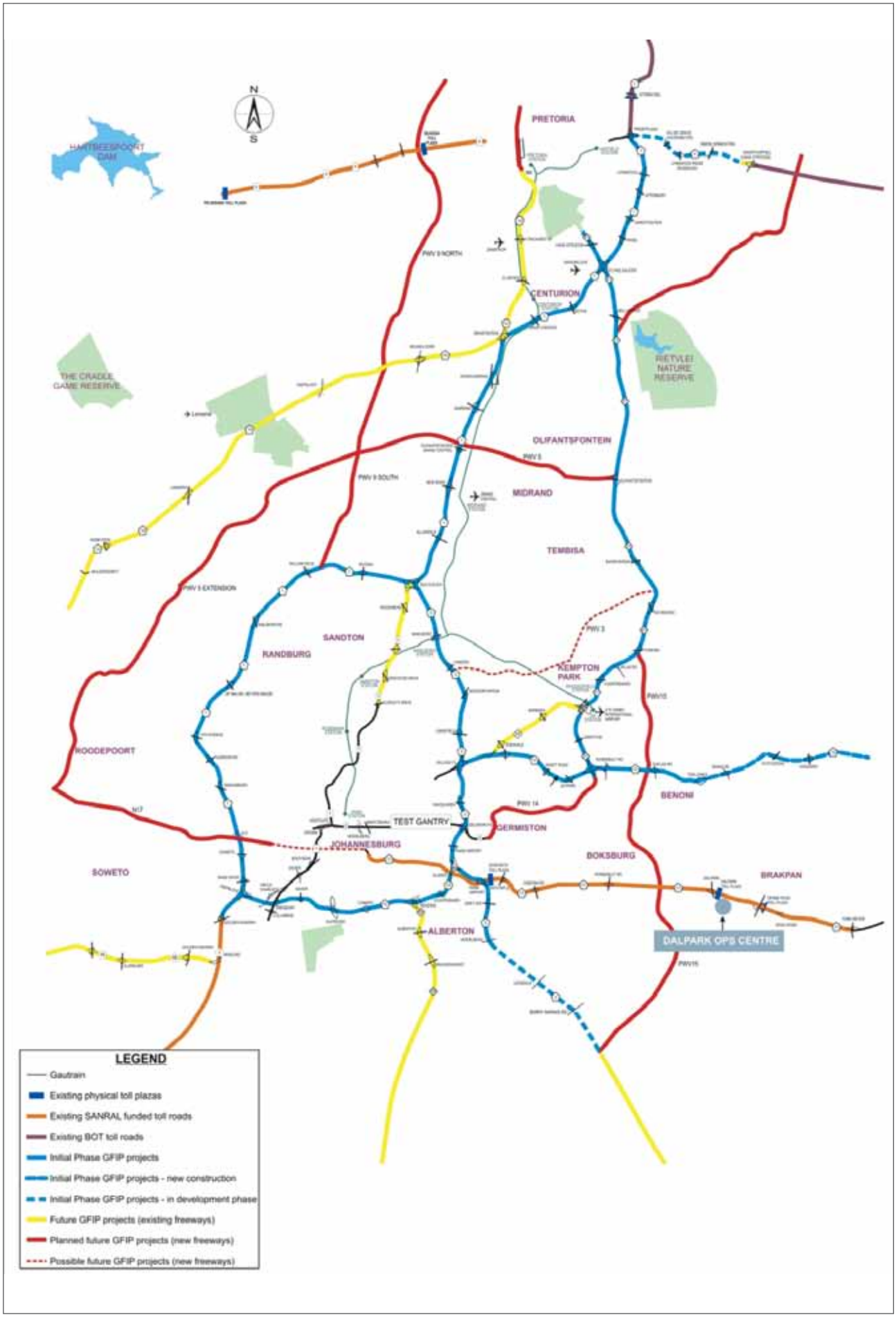
The GPS data obtained was downloaded and processed using purpose-built software for filtering, smoothing and geographic information system (GIS) matching of trips and routes. It was then analysed and the driving behaviour of the two driver populations compared in terms of the total distance travelled, spatial patterns and temporal variation. The detailed nature of the GPS data also permitted the estimation of fuel consumption at a very disaggregate level (by link and time of day), and the identification of differences between user groups, which have significant implications for transport and energy policy.

Daily vehicle kilometres of travel

The results of the average daily vehicle kilometres of travel (VKT) for different income groups in the private car sample are depicted in Figure 2. Consistent with travel behaviour theory, the lowest travel activity occurred in the lowest income category, with an average daily distance travelled of about 20 km. The mid-range income group was found to have the highest driving activity. The VKT was found to reduce again by about 20% for higher income groups.

The reasons for these trends can be found in the fact that low-income drivers cannot always afford to travel long distances. High-income users can afford to travel long distances, but also have maximum choice of housing and employment location. They seem to use this flexibility to improve their proximity to jobs and other activities. Medium-income drivers seem to be worst off. While they can afford to travel long distances, they also seem less able to avoid them.

For commercial vehicles, the VKT was much higher. On average, intra-provincial vehicles travel 165 km per activity chain, which increases to 532 km per activity chain for inter-provincial vehicles. The average number of activities per chain was



→ *Figure 1: Freeway network in Gauteng, South Africa (Source: South African National Roads Agency Ltd)*

9.2 for intra-provincial vehicles and 8.6 for inter-provincial vehicles. With transport costs making up a sizable proportion of total logistics costs, companies aim to maximise their fleet utilisation. Activity chains with a high number of activities are indicative of such optimisation efforts.

Road type and time of day

Figure 3 categorises the VKT for different income groups by the type of road on which travel occurs. Overall, about a third of private car use in Gauteng occurs on the freeway network, and only 22% on the street network. There is a clear relationship between personal income and the type of road used. Freeway use rises with income, with the most affluent drivers spending more than twice the proportion of kilometres on freeways than the lowest income category. This is most likely related to the fact that the freeway network is designed to serve the commuting needs of higher-income drivers better than those of lower-income neighbourhoods.

In comparison, private cars and commercial vehicles differ in their use of road types. It was found that private cars and intraprovincial commercial vehicles spend similar proportions of their VKT on the freeways, while commercial vehicles make greater use of arterial roads and less use of local streets.

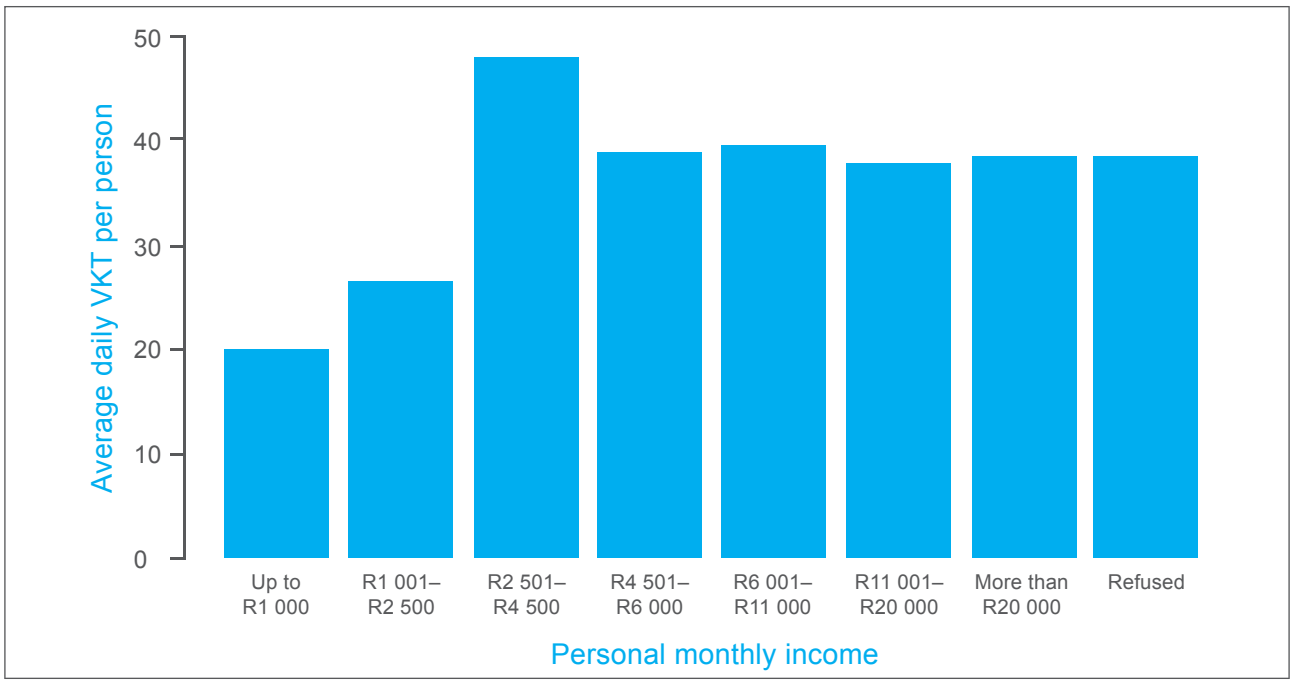


Figure 2: Average daily VKT of private car users, by income category

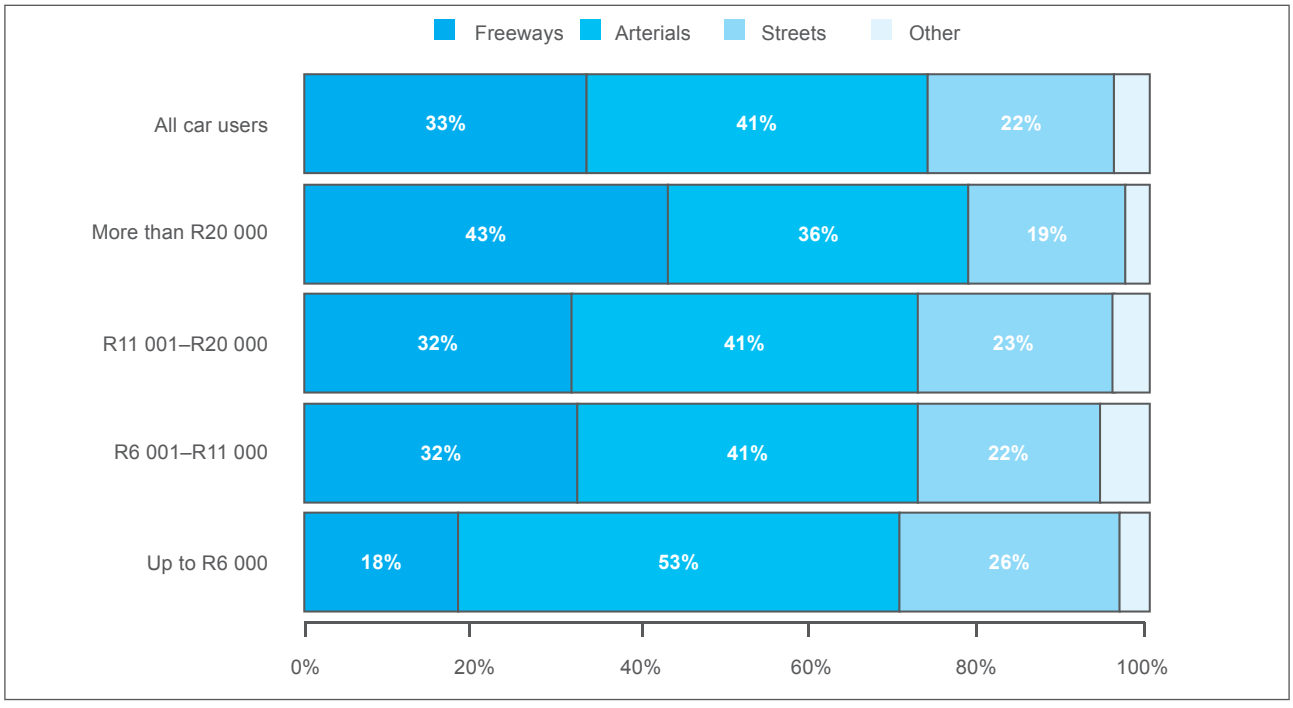


Figure 3: Distribution of daily VKT of private car users per road type

In contrast, interprovincial vehicles undertake more long-haul trips and show higher VKT on the freeway and arterial network.

Table 1 shows the share of freeway VKT by private and commercial vehicles throughout the day. Time-of-day patterns are important, as fuel consumption varies with speed and congestion levels. Higher-income drivers tend to concentrate more of their freeway travel in the peak periods, while low-income drivers make more use of shoulder and off-peak periods. Average travel speeds are marginally lower in the peak than in the off-peak periods, and much lower on arterial and local streets.

Day-to-day variability

Recent research has focused on the day-to-day variability of travel, arguing that habit and variability are important dimensions of travel behaviour. Multi-day GPS data is useful to determine the regularity and variability of travel, at both aggregate and route level.

To measure the general level of variability in daily travel activity, a coefficient of variation (CoV) for the daily VKT for each vehicle was calculated.

A CoV value of zero corresponds to no variation. The larger the CoV for a vehicle, the more the daily travel varied from day to day. For private vehicles, the GPS records across three consecutive weekdays were used. For commercial vehicles, three consecutive weekdays were arbitrarily chosen, with typical traffic patterns, to calculate the CoV.

The average CoV was shown to vary between vehicle classes, and also within each class. The most important finding is that day-to-day variation is higher for private vehicles than for commercial vehicles, and that, among private vehicles, the highest variability is found in the lower-income groups.

For interprovincial commercial vehicles, the CoV varied between 0 and 1.73, with a median of 0.54 and a mean of 0.60. The behaviour of intraprovincial vehicles was more consistent, with a lower median of 0.39 and a mean of 0.47. The fact that commercial vehicles often perform routine deliveries may explain the low variation. The average CoV for private cars, across all income groups, varied between 0 and 1.59, with a median of 0.69 and a mean of 0.70, which was significantly higher than the day-to-day variation of commercial vehicles.

A second measure of variability looks at the day-to-day variation at the route level. The researchers found that only 47% of freeway users in the sample used the same freeway section on more than one day. The rest showed no repetition in their route choices.

Estimating disaggregate fuel consumption patterns

In order to estimate fuel consumption at the level of the individual vehicle, link and time of day, the following model was used:

$$c_{nkt} = d_{nk}.b_n.f(v_{nkt})/100$$

Where:

c_{nkt} = litres of fuel consumed by vehicle *n* on link *k* at time *t*
d_{nk} = distance travelled by vehicle *n* on link *k* (in kilometres)
b_n = base fuel consumption rate for vehicle *n* (in litres per 100 km)
= fuel efficiency adjustment factor $f(v_{nkt})$ for vehicle *n* travelling at speed

Fuel consumption is thus dependent on the type of vehicle, the link distance and the travel speed. Consequently, fuel consumption would vary by the type of road used and the time of day (depending on congestion levels).

Table 2 shows the results of the fuel calculations by user group and road type. Fuel consumption rates are highest on streets, followed by freeways and then arterials. Fuel consumption is slightly higher during

→ *Table 1: Time-of-day distribution of VKT and speed on Gauteng roads*

	Morning and afternoon peaks (06:00–10:00 and 14:00–18:00)	Off-peak (05:00–06:00, 10:00–14:00 and 18:00–21:00)	Night (21:00–05:00)	Total
Percentage of VKT on freeways by time of day				
Private car users				
Income[1] up to R6 000	47%	39%	14%	100%
R6 001 to R11 000	54%	35%	11%	100%
R11 001 to R20 000	61%	34%	5%	100%
R20 001 and up	59%	35%	6%	100%
Refused to answer/ Did not know	52%	42%	6%	100%
Commercial vehicles				
Intraprovincial heavy vehicles	50%	44%	6%	100%
Interprovincial heavy vehicles	50%	44%	6%	100%
Average speed per road type (km/h)				
Freeways	87.5	97.1	--	--
Arterials	46.5	47.9	--	--
Streets	37.9	39.4	--	--

1. Personal monthly income reported in GPS survey. The dash indicates values that are not estimated.

off-peak periods, but the difference is negligible for cars and trucks. Trucks have much higher fuel consumption rates than passenger vehicles, but contribute only 12% to the total fuel bill. Among car users, drivers in the highest income group have the highest fuel consumption rates due to their use of larger, less fuel-efficient vehicles. Drivers in the lowest income bracket also have high fuel consumption rates.

A "recovery ratio" was also calculated, which is relevant to the road financing debate, as fuel tax revenues contributed by a group are proportional to their total fuel consumption. If fuel levies are seen as a user payment for road use, these revenues should be on par with the amount of road use. A recovery ratio of less than 1.0 indicates that a group contributes less fuel taxes than their share of VKT demands. This is the case for car users. Commercial vehicles pay about two and a half times their share of VKT. Among car users, higher-income drivers tend to have recovery ratios above 1.0. The exception is drivers in the lowest income group. This suggests that they are doubly penalised. Not only do they consume more fuel per kilometre by travelling on more congested streets, but their taxes go towards upgrading other parts of the network (arterials and freeways) that are used more frequently by other drivers.

Conclusion

The study found that high congestion and low speeds on residential streets lead to higher fuel use and higher taxation. Improving local street networks would be an effective method of reducing energy consumption and travel expenditure. Further research is needed to accurately identify and allocate benefits and costs, relating not only to fuel costs, but also to multiplier effects and intangible benefits, such as reliability and safety. These factors influence the acceptability and fairness of road funding mechanisms, which are under pressure worldwide.

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References

Joubert, JW & Axhausen, KW. 2011. Inferring commercial vehicle activities in Gauteng, South Africa. *Journal of Transport Geography*, 19(1).

Venter, C. 2011. Transport expenditure and affordability: The cost of being mobile. *Development Southern Africa*, 28(1).

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Table 2: Fuel consumption rates and recovery ratios per user group in Gauteng

	Average fuel consumption rate (litres/100 km)					Recovery ratio (percentage of fuel consumed / percentage of VKT)		
	Freeways	Arterials	Streets	Peak	Off-peak	Freeways	Arterials	Streets
Private car users								
Income[1] up to R6 000	8.78	9.33	10.91	9.64	9.66	0.87	0.92	1.08
R6 001 to R11 000	9.12	8.93	9.54	9.05	9.25	0.90	0.88	0.94
R11 001 to R20 000	8.67	8.67	9.33	8.76	8.94	0.86	0.86	0.92
R20 001 and over	10.19	9.85	10.21	10.02	10.12	1.01	0.97	1.01
Refuse to answer/ Did not know	9.57	9.10	9.74	9.32	9.51	0.95	0.90	0.96
All car users	9.30	9.14	9.92	9.34	9.45	0.92	0.90	0.98
Commercial vehicles								
Intraprovincial	24.35	25.04		25.40	24.15	2.41	2.48	
Interprovincial	24.37	25.06		24.83	24.49	2.41	2.48	
All commercial vehicles	24.36	25.05		25.09	24.34	2.41	2.48	
Total: All vehicles	10.30	10.02		10.11	10.12	1.02	0.99	

2 Personal monthly income reported in GPS survey.