Linking CGE and specialist models: Deriving the implications of highway policy using USAGE-Hwy

Manuscript Details

Manuscript number	ECMODE_2017_479
Title	Linking CGE and specialist models: Deriving the implications of highway policy using USAGE-Hwy
Article type	Full Length Article

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Keywords	Linked modelling; CGE modelling; highway modelling; highway spending policy
Taxonomy	Government Expenditure on Infrastructure, Evaluation of Microeconomic Policy, Computable General Equilibrium Model

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Deriving the implications of highway policy using USAGE-Hwy

Abstract

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JEL Classification Codes: C68; L92

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Acknowledgements:

We thank the U.S. Department of Transportation (DOT) and the Australian Research Council (ARC grant no. DP140100476) for financial support. We thank Sean Puckett from DOT for providing results from the HERS model. The analysis and conclusions in the paper are entirely our own. They do not necessarily reflect the views of DOT, the ARC, or any officers in these organizations.

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1. Introduction

The field of computable general equilibrium (CGE) modelling started over 50 years ago with Leif Johansen's study of Norway.[1] His work and most CGE modelling since then has been based on standard economic assumptions (e.g. constant returns to scale, pure competition) implemented with standard economic data sources (e.g. input-output tables and national accounts published by government statistical agencies).

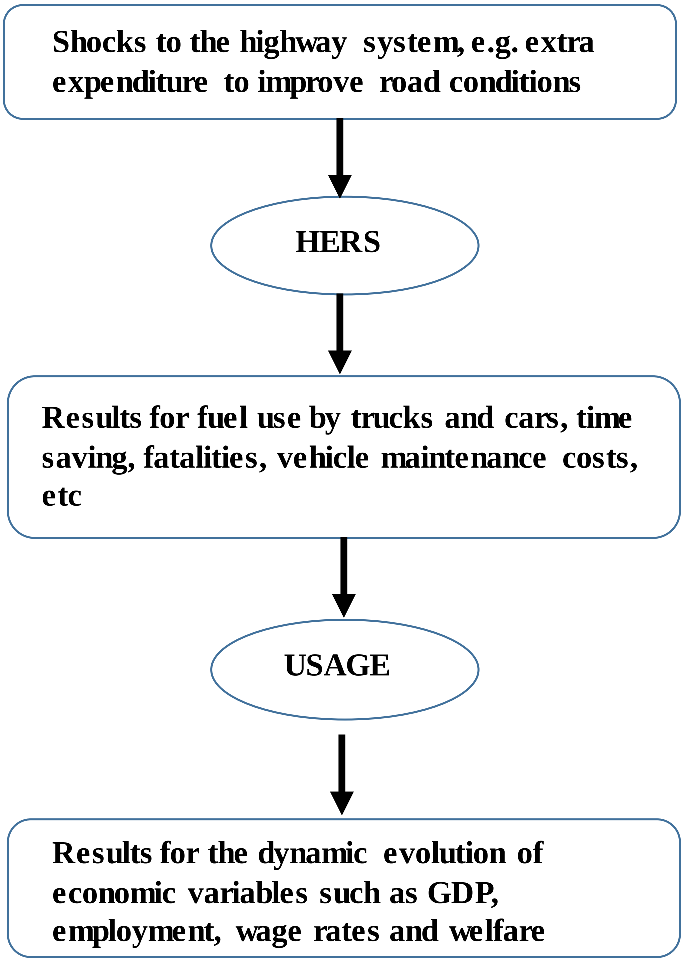
However, there is a large body of specialist theory and empirical information in such areas as energy, environment and transportation that can be brought to bear in a CGE framework. Examples of studies in which outputs from specialist models have been taken into a CGE model include, Adams and Parmenter (2013), Dixon and Rimmer (2014) and Harback *et al.* (2016). In the first two studies, results from electricity models were passed through CGE models to derive implications of greenhouse policies for GDP, employment, wage rates and other economic variables. In the third study, results from an air traffic model were passed through a CGE model to derive economic implications of NextGen infrastructure improvements to airports. The objective of this paper is to contribute to this literature by providing a case study in which outputs from an engineering-based model of U.S. highways are passed through a CGE model to derive economic results that are informed by both types of modelling. The highway model is HERS (the Highway Economic Requirements System) and the CGE model is USAGE (U.S. Applied General Equilibrium). The relationship between the two models is shown diagrammatically in Figure 1.1.

Among CGE model, USAGE is relatively detailed. In this paper we start with a version which identifies 62 commodities produced by 59 industries. Versions of the model with even greater levels of detail are available. The U.S. International Trade Commission (2004, 2007, 2009, 2011 & 2013), for example, uses versions of USAGE with up to 500 industries. Nevertheless, CGE models based on standard input-output data almost never contain the level of detail in the area of interest required for them to be integrated successfully with a specialist model. Almost always the standard CGE model must be extended.

In section 2 we describe the process of extending USAGE so that it could accept inputs from HERS for detailed highway-related variables such as: fuel use per mile travelled by trucks and by cars; time taken in commuting in private cars, buses and other transport; time taken in business travel and freight delivery; road fatalities; and vehicle maintenance costs. We refer to the version of USAGE with these extensions as USAGE-Hwy.

[1] See Johansen (1960, 1974). For a description of his achievement and a review of developments since then see Dixon and Rimmer (2016).

Figure 1.1. From Highway shocks to economic implications



Section 3 describes HERS output that is taken into USAGE-Hwy. This output shows the effects on highway-related variables of an illustrative program of increased highway and bridge (H&b) expenditure over the period 2010-2040.

Section 4 reports and explains results for three USAGE-Hwy simulations of the macroeconomic effects of increased expenditure on H&b. The simulations differ in their assumptions concerning financing of the extra H&b expenditure. Three further simulations are provided to assess the sensitivity of the welfare effects of H&b expenditure to variations in assumptions concerning the link between travel time and labor supply. Concluding remarks are in section 5.

2. Creation of USAGE-Hwy

2.1. The starting point: the USAGE model

As in nearly all CGE models, in USAGE optimizing behaviour governs decision-making by firms and households. Industries minimize the costs of output subject to constant-returns-to-scale production functions, treating input prices as given. Households also take prices as given and choose their consumption bundle to maximize utility subject to their budget constraint. Domestic and imported goods are treated as imperfect substitutes. Export demands for US commodities are modelled as inversely related to their foreign-currency prices. Explicit recognition is given to tax, transport and other margins that separate purchasers' prices from basic and producer prices. As explained in Dixon *et al.* (2013), the main data for the model comes from input-output tables published with conventional industrial classifications by the U.S. Bureau of Economic Analysis.

USAGE is normally run on a year-on-year basis, showing how the economy evolves from year t to year t+1 to year t+2, etc. It incorporates three types of dynamic mechanisms: capital accumulation; liability accumulation; and lagged adjustment processes. An industry's capital stock at the start of year t+1 is its capital at the start of year t plus its investment during year t minus depreciation. Investment during year t is determined as an increasing function of the expected rate of return on the industry's capital. Liability accumulation is specified for the public sector and for the foreign accounts. Public sector liability at the start of t+1 is public sector liability at the start of t plus the public sector deficit incurred during t. Net foreign liabilities at the start of t+1 are specified as net foreign liabilities at the start of t plus the current account deficit in t plus the effects of revaluations of assets and liabilities caused by changes in price levels, the exchange rate and other factors. Lagged adjustment processes are specified in USAGE for labor market variables. For example, wages adjust sluggishly to eliminate gaps between supply and demand for labor.

Simulations with USAGE models consist of two runs: a baseline run representing a business-as-usual evolution of the economy; and a policy run which shows the evolution of the economy with the addition of policy shocks to the baseline. Comparison of the two runs shows the effects of the policy.

In the rest of this section we explain how we built USAGE-Hwy. This required the creation of a revised input-output database for 2010 with 6 new industries and commodities: Highways and bridges; Street repairs; Private road transport; Vacation transport; Commuter transport; and Household car repairs. These additions took the industry/commodity dimensions from the original 59/62 to 65/68. We also introduced new treatments of travel time and welfare.

The overarching strategy in moving from USAGE to USAGE-Hwy is to confine the changes to the database. We create new industries and commodities but we don't change the model's mathematical theory. We introduce radical changes in the treatments of substitution between transport modes and time use in travel. But we don't change the mathematical forms of production functions, utility functions, demand/supply balance conditions, zero profit conditions, and dynamic accumulation and lag equations. We change the dimensions of the model, but we don't change the code that presents the model to the computer for solution. This means that once the new database for 2010 is created, then USAGE-Hwy is ready to run using the USAGE programs.

2.2 Splitting construction

We split the single Construction industry into 3 separate industries: Highways and bridges; Street repairs; and Other construction.

In 2005 (the last year for which we have input-output data at the detailed 500 sector level), expenditure on Highways and bridges (H&b) was $89 billion representing 6.1 per cent of total sales of Construction. We assumed that H&b account for 6.1 per cent of construction expenditure in 2010, the base year for USAGE-Hwy. Thus, in creating the USAGE-Hwy database for 2010 we moved 6.1 per cent of construction inputs into the H&b industry. We gave the H&b inputs the same structure as in the 2005 detailed input-output database. We sold all of the output of H&b to Government and made a corresponding reduction in Government purchases of Construction.

In 2005, expenditure on Street repairs was $43b representing 2.9 per cent of total sales of Construction. We made a Street repairs industry following the same steps as for H&b.

2.3 Creating a household car repair (HCR) industry and commodity

Car repairs in our 2005 data represent 22.5 per cent of the purchases of Miscellaneous services by households. We created a Household car repair (HCR) industry for the 2010 USAGE-Hwy database with output worth 22.5 per cent of the 2010 purchases of Miscellaneous services by households. We gave the new HCR industry an input structure as close as possible to that of the Car repair industry in the detailed 2005 database. We rebalanced by reducing inputs to Miscellaneous services, reducing sales of Miscellaneous services to households and selling all of the new HCR output to a new PRT industry (as discussed immediately below).

2.4. Creating Private road transport (PRT), Commuter travel (CT)and Vacation Travel (VT) industries and commodities

We formed a Private road transport (PRT) industry and commodity. Intermediate inputs to this industry consist of HCR, Motor fuel and Motor vehicles. In creating the database, we transferred these inputs out of private consumption and the Vacation industry. By treating cars as an intermediate input we are saying that an increase in PRT output (miles of travel) uses up cars. We sold the output of PRT to two new industries, Commuter transport (CT) and Vacation transport (VT), in proportion to the purchases in the original USAGE database of motor fuel by Households and the Vacation industry (an industry that produces vacations in the U.S. for resident households with inputs from Hotels, Restaurants and transport services). The CT industry also buys the original household purchases of Buses, taxis & rail services (PassengerTrans), within-U.S. air transport (AirInternal) and within-U.S. water transport (WaterInternal). The VT industry buys the original purchases by the Vacation industry of Buses, taxis & rail services, AirInternal and WaterInternal. As can be seen from Figure 2.1, the output of CT is sold to households. The output of VT is sold to the Vacation industry, which in turn is sold to households.

CT and VT are examples of mixing industries. These artificial industries are a convenient mechanism for introducing desired substitution possibilities without altering or complicating the mathematical structure of the model. For example, by selling PRT output together with household purchases of other transport services to CT and VT, we can easily allow for substitution between transport modes in satisfying household demands for commuter transport and vacation transport services.

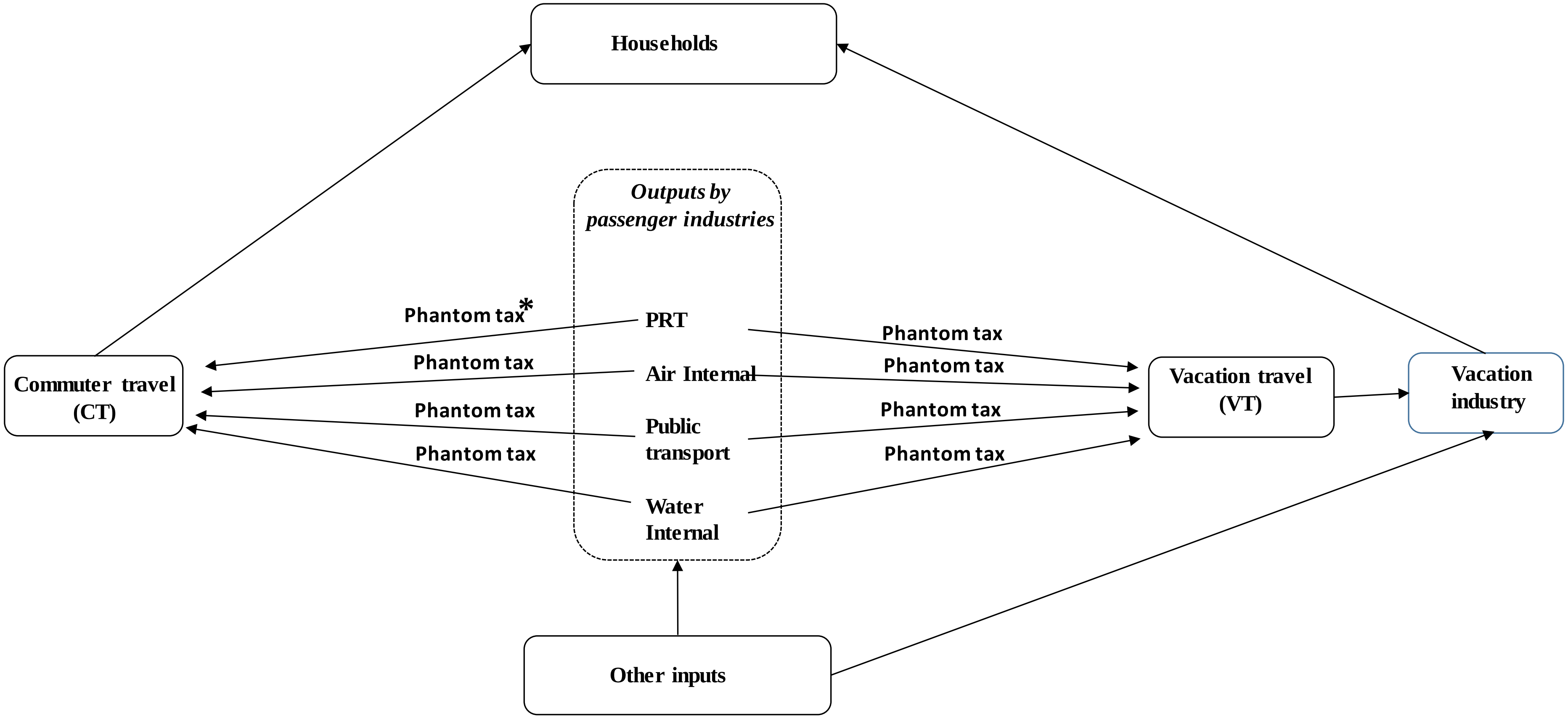
2.5. Travel time and associated costs

A major motivation for road improvement is to save travel time. This can be handled in a straightforward manner for trucking services as a change in productivity for the Trucking industry. But what about passenger travel where time expended is not paid for by any industry and is not recognized in standard input-output data?

As detailed below, we made estimates for the base year (2010) of passenger time spent in various transport modes: AirInternal, Private road, Buses etc and WaterInternal. We introduced equations to explain movements in travel times in terms of volume of travel. We also included variables to allow for changes in travel time per passenger mile. In the case of travel conducted on highways, these variables were used to introduce results from HERS.

To get passenger travel time recognized in USAGE-Hwy as a cost, we made the industries that buy passenger services pay a phantom tax equal to the value of the time that households spend in travel. As indicated in Figure 2.1, the sales on which phantom taxes are levied are those to CT and VT of AirInternal, PRT, Public transport and WaterInternal. In this way, we

Figure 2.1. Production and sales of passenger services in USAGE-Hwy



* As explained in the text, phantom taxes are used to introduce the costs of travel time

introduced the idea that the cost to households of using different modes of transport includes not only the cost of producing the transport services (covered by fares and private purchases of gasoline etc) but also the value of the time taken in travel.

Who collects the phantom tax? The answer is no one. The role of a phantom tax is to boost the price of the commodity (in this case a transport service) on which it is charged. This facilitates the modelling of price signals: it allows USAGE-Hwy to represent substitution by households between transport modes in response to a change in travel time for one mode relative to others. Our concern with substitution explains why it was necessary to consider time use in *all* travel modes even though our focus is on highways.

The final issue to be decided with regard to travel time is what happens to travel time savings. The most obvious possibilities are that households increase their labor supply or their leisure. Metz (2008, p. 322) raises another possibility: that households use potential travel time savings associated with improved highways to travel further. However, we don't investigate this possibility. Instead, in our central simulations we assume that travel time savings are absorbed by a combination of extra labor and leisure (details below), and in sensitivity simulations we assume that all time savings are used for leisure.

Air transport

USAGE contains two air transport industries: AirInternal that provides passenger and freight air services within the U.S., and AirExternal that provides these services internationally. Our focus is on passenger services supplied by AirInternal. These are potentially substitutable for other transport modes especially in Vacation travel (VT).

After the adjustments we have already described, sales of AirInternal in the 2010 database are as follows: 25 per cent to margins (freight), 34.4 per cent to VT, 0.6 per cent to CT and the rest (40 per cent) to other industries. The sales of AirInternal for margin purposes were handled satisfactorily in USAGE: substitution was allowed against road, rail and water transport services and no modification was made to this treatment in USAGE-Hwy. To handle AirInternal sales to VT and CT we have, as outlined below: (a) put in substitution elasticities between intermediate inputs in the VT and CT industries; (b) decided how much time is taken by households in using the services of AirInternal that are intermediate inputs to VT and CT; (c) decided what values to place on this time; and (d) decided how much of this time to treat as a deduction from labor supply and how much as a deduction from leisure. With regard to the 40 per cent of sales of AirInternal that go to other industries we retained the standard USAGE treatment. We assumed that industries flying employees cannot substitute to other modes of transport.

On (a), we adopted a substitution elasticity of 2. On (b) we assumed that each journey takes 5 hours (includes getting to the airport, waiting around, flying and ground transport to destination). We assumed that the number of passenger journeys supplied by AirInternal is 424.5 million. This is 566*0.75, where 566 million is the USAGE number for all airline journeys by U.S. residents and 0.75 is our estimate of airline journeys undertaken by U.S. residents using AirInternal services, rather than AirExternal services. Thus we assumed that AirInternal sales to VT and CT cover 194.7 [=424.5*0.344/(1-0.25)] and 3.4 [= 424.5*0.006/(1-0.25)] million journeys, where 0.344/(1-0.25) is the share of *passenger* sales by AirInternal that goes to VT and 0.006/(1-0.25) is the share of passenger sales by AirInternal that goes to CT. On our 5 hour assumption, U.S. residents devote 990 [= (194.7+3.4)*5] million hours to using the services of AirInternal in generating domestic

Table 2.1. Quantities and values of waiting/travelling in 2010

	Value of travel time ($ per hour)	Time lost (m. of hours)	Fraction of time lost deduced from labor supply in central sims	Deduction from labor supply (m. person years)	Phantom tax on sales ($m)
	(1)	(2)	(3)	(4)=(2)*(3)/2000	(5) = (1)*(2)
Sales to VT					
AirInternal	5	973	0.10	0.0487	$4,865
PRT	5	13,448	0.10	0.6724	$67,241
PublicTrans	5	5,910	0.10	0.2955	$29,550
WaterInternal	0	0	0.00	0.0	0
Sales to CT					
AirInternal	15	17	0.25	0.0021	$255
PRT	15	61,263	0.25	7.6579	$918,945
PublicTrans	15	8,704	0.25	1.0881	$130,568
WaterInternal	15	384	0.25	0.0479	$5,753

vacations (973m hrs) and commuting (17m hrs). On (c), we assumed that households value vacation travel time at $5 an hour and commuter time at $15 an hour. We have chosen values well below average wage - we think this realistically reflects what people would be prepared to be paid to wait around doing not much. These two values ($5 and $15) are closely compatible with an average value for travel time of $11.89, the value recommended by the U.S. Department of Transportation. On (d), we decided for our central simulations to treat 10 per cent of VT-associated waiting/travelling time as potential labor supply. With 2000 hours representing the labor supply of a person in a year (40 hours per week for 50 weeks), we deduct 0.0487 [= 0.10*(973/2000)] million person years from labor supply on account of AirInternal waiting/travelling time associated with VT. For CT-associated waiting/travelling time we treat 25 per cent as potential labor supply: that is we deduct 0.0021 [= 0.25*(17/2000)] million person years from labor supply.

As shown in Table 2.1, with 973 million hours valued at $5 an hour we imposed a phantom sales tax of $4865 million on sales of AirInternal to VT. With 17 million hours valued at $15 an hour we imposed a phantom sales tax of $255 million on sales of AirInternal to CT. In simulation, we drive the collection of these sales taxes by the nominal wage rate, the quantities of sales of AirInternal to VT and CT, and travel time per quantity of sale. For sales of AirInternal, travel time per quantity is held constant in the simulations of highway improvement discussed in section 4.

Private road transport (PRT)

The database for DOT's version of the HERS model shows that vehicle miles travelled (VMT) for PRT in 2010 was 2,253,110 million. The HERS valuation of travel time is $437.7 per 1,000 VMT, giving a total cost of PRT travel time in 2010 of $986,186m (= 2,253,110*437.7/1000). The HERS database doesn't throw light on either the hourly cost of time (which we assume is $15 for CT and $5 for VT) or on the proportion of PRT travel time that should be treated as a deduction from labor supply. As for air transport, in our central simulations we assume 25 per cent deduction from labor supply for travel time used in CT and 10 per cent for VT.

We split HERS' 2,253,110 million PRT miles between VT and CT in proportion to motor fuel sales to the Vacation industry and to households in the original USAGE database. This gives VT travel for PRT at 405,564m miles and CT travel at 1,847,546m miles. Continuing to assume hourly travel time costs of $5 per hour for VT and $15 per hour for CT, we can hit the

HERS cost number by assuming that the average speed of vehicles is 30.16 miles per hour. This gives time taken in VT travel as 13,448m hours (=405564/30.16) and time taken in CT travel as 61,263m hours (=1847564/30.16) with corresponding costs of $67,241m (=13448*5) and $918,945m (=61263*15). As can be seen in Table 1, these costs are treated as phantom taxes on sales of PRT to VT and CT. In simulations, these tax collections are driven by the nominal wage rate, the quantities of sales of PRT to VT and CT, and travel time per quantity of sale. Changes in travel time per sale of PRT are an important part of the highway improvement simulations discussed in section 4.

Buses, taxis and rail (PublicTrans)

After the adjustments so far, 27.8 per cent of sales of PublicTrans in the 2010 database are to VT and 40.9 per cent to CT. We make no change to the standard USAGE modelling of the remaining 31.3 per cent. These sales go to other industries in which we assume there is no substitution between inputs of PublicTrans and other intermediate inputs.

The values of consumer purchases and Vacation purchases of PublicTrans in the original input-output data were $34,818m and $23,640m. We assume that the average fare per hour in 2010 for PublicTrans journeys was $4. This give total travel times associated with CT and VT of 8,704.5 and 5,910 million hours. Valued at $15 and $5, these hours translate into phantom taxes of $130,567.5 million on sales of PublicTrans to CT and $29,550 million on sales of PublicTrans to VT. In simulations, collections of these taxes are driven by the nominal wage rate, the quantity of sales of PublicTrans to VT and CT, and travel time per sale (held constant for PublicTrans sales in the simulations in section 4).

As can be seen in Table 2.1, for PublicTrans in our central simulations we continue to assume that 25 per cent of waiting/travelling time associated with CT and 10 per cent associated with VT are potential additions to labor supply.

Water transport

After the adjustments so far, WaterInternal sales in the 2010 database are as follows: 49.3 per cent to margins, 21.2 per cent to VT, 3.7 per cent to CT and the rest (25.8 per cent) to other industries. As with the previously discussed transport modes, we left the treatment of margin sales and sales to industries apart from CT and VT unchanged from the original USAGE treatment.

The value of consumer purchases and the sales to the Vacation industry in the original input-output data were $1,534m and $8,734m. Again, using the fare of $4 per hour of travel, we deduced that there were 383.5 million passenger hours of travel associated with CT. Valuing these hours at $15 per hour gives $5,753 million as the phantom tax on WaterInternal sales to CT. For VT, we assumed that WaterInternal is an integral part of a vacation. Thus we do not need to calculate associated travel time costs or potential labor supply/leisure effects. For the central simulations we treated 25 per cent of WaterInternal waiting/travelling time associated with sales to CT as potential labor supply.

2.6. Elaborating the measure of welfare

In most USAGE simulations we assess the welfare effect in year t of a policy change by looking at the percentage deviation that the change causes in real household consumption. Algebraically, we compute

$$W_t = \sum_c S_t(c) * \left[\frac{X_t^P(c) - X_t^B(c)}{X_t^B(c)} \right] * 100 \qquad (2.1)$$

where

W_t is the welfare effect in year t expressed as a percentage of baseline consumption;
$X_t^P(c)$ and $X_t^B(c)$ are the levels of household consumption of commodity c in the policy and baseline simulations, that is the simulations with the policy and without the policy; and
$S_t(c)$ is the share of total household expenditure devoted to commodity c.

There are several possibilities for evaluation of $S_t(c)$. The leading cases are the Laspeyres variant in which $S_t(c)$ is taken from the baseline simulation; and the Paasche variant in which $S_t(c)$ is a hybrid share that uses baseline quantities and policy prices.

Equation (2.1) is closely related to two other welfare concepts: equivalent variation (EV) and compensating variation (CV). With Laspeyres shares, (2.1) is an overestimate of EV and with Paasche shares (2.1) is an underestimate of CV (see for example Dixon and Rimmer (2002, p. 210). However, CV, EV and other variants of (2.1) normally give similar results. For simplicity, we usually use the Laspeyres variant and have done so for USAGE-Hwy.

For USAGE-Hwy we make three modifications to (2.1). First, we delete medical expenditures from the list of commodities. Highway projects cause changes in road-related medical expenditures. If a project causes these expenditures to increase, we want this to be recorded as a negative influence on welfare. With medical expenditures left out of the commodity list, an increase in these expenditures reduces income available for expenditures on other commodities thereby leading (2.1) to show a reduction in welfare. Similarly, if a highway project causes medical expenditures to fall, then (2.1) records a welfare increase via additional expenditures on other commodities.

Highway projects change the number of road fatalities. The second modification that we made to (2.1) allows for road fatalities valued as a welfare reduction of \$6.8m (2010 prices) per fatality. This was the standard valuation used by the US Department of Transportation in 2010.

The third modification concerns leisure. By changing travelling time, highway projects can potentially change leisure time available to households. We recognize this possibility in USAGE-Hwy by including in the evaluation of the welfare effects of highway projects time saved in commuter travel by any mode valued at 0.4348 times the average wage rate and time saved in vacation travel by any mode valued at 0.1449 times the average wage rate. In our 2010 data, 0.4348 times the average wage rate corresponds to \$15 per hour and 0.1449 times the average wage rate corresponds to \$5 per hour. By using the average wage rate in our simulations, the hourly value of time saved is automatically updated through time for changes in prices and real wage rates. Some of the potential leisure generated by reduced travel times may be used up by extra work, allowing extra consumption. The extra consumption is allowed for in the standard welfare function, (2.1). But we should also allow for the disutility of work which offsets some of the benefits of extra consumption. In the modified welfare function used in USAGE-Hwy we value the disutility of extra work at 0.4348 times the average wage rate (\$15 an hour in 2010).

With these three modifications we write the welfare effect in year t of a policy change (e.g. extra expenditure on highways) as:

$$\begin{aligned} 0.01*W_t = \sum_{c\neq Med} S_t^{\#}(c)*\left[\frac{X_t^P(c)-X_t^B(c)}{X_t^B(c)}\right] - \frac{6.8*CPI_t^{\#B}}{CPI_{2010}^{\#B}}*\frac{d\_fatal_t}{AGGCON_t^{\#B}} \\ + \frac{d\_v\_timesave_t}{AGGCON_t^{\#B}} - \frac{d\_v\_employ\_disutility_t}{AGGCON_t^{\#B}} \end{aligned} \tag{2.2}$$

where

$S_t^{\#}(c)$ is household expenditure on commodity c expressed as a share of total household expenditure excluding medical expenses;

$AGGCON_t^{\#B}$ is total household expenditure excluding medical expenses in the baseline;

d_fatal_t is the policy-induced change in road fatalities in year t;

$d\_v\_employ\_disutility_t$ is the policy-induced change in hours of work in year t valued at 0.4348 times the average wage ;

$d\_v\_timesave_t$ is timesaving in travel valued at 0.4348 times the average wage for commuter travel and 0.1449 times the average wage for vacation travel; and

$CPI_t^{\#B}$ is the baseline level of the CPI (excluding medical expenditures) in year t.

3. Simulating the effects of increased H&b spending: the shocks

To illustrate the application of USAGE-Hwy we simulate the effects of a program of increased highway expenditure. Consistent with Figure 1.1, our colleagues at the U.S. Department of Transportation fed into HERS a scenario of increased highway expenditures. From HERS they derived effects on vehicle operating costs, travel time etc. These effects, together with the expenditure scenario were fed into USAGE-Hwy to derive results for economic variables such as GDP, employment and welfare.

3.1 Input to HERS: Public expenditure on highways and bridges (H&b)

Chart 3.1 shows baseline and policy (increased expenditure program) paths for highway expenditures from 2010 to 2040. It also shows differences between these two paths expressed as percentages of baseline GDP. As can be seen from the chart, the policy involves a boost in H&b expenditures out to 2031 with the peak expenditure boost being 0.135 per cent of GDP in 2020. Beyond 2031, the policy levels of H&b expenditure are below those in the baseline. In our simulations extra H&b expenditures are treated as additional government purchases from the H&b industry.

3.2. Outputs from HERS used as inputs to USAGE highway

Road maintenance savings

The HERS results that we received from the US Department of Transportation imply that additional infrastructure expenditure (investment) generates savings in road maintenance. These savings are shown in Chart 3.2. Relative to the additional highway expenditures (Chart 3.1), the maintenance savings in Chart 3.2 are negligible. In our simulations we treat maintenance savings as deductions from the additional infrastructure expenditure. For example, in 2020 the additional infrastructure expenditure (the gap between the policy and baselines in Chart 3.1) is $28,381m. The maintenance savings in 2020 are $81m. Thus our shock in USAGE-Hwy for net expenditure in 2020 is $28,300m. By treating saving of road maintenance as a deduction from additional infrastructure expenditure, we assume that the structure of inputs to road maintenance is the same as that for infrastructure expenditure. This is probably a reasonable assumption: both infrastructure and maintenance are highly labor intensive. In any case, as already mentioned, maintenance savings are minor.

Vehicle operating costs

As shown in Chart 3.3, the HERS results imply that additional highway investment reduces operating costs of vehicles per mile travelled. These costs cover fuel, oil, tyres and vehicle maintenance. The savings are particularly pronounced for passenger vehicles, reaching 1.1 per cent in 2020. In USAGE-Hwy simulations we introduced the savings shown in Chart 3.3 as uniform savings across all intermediate inputs in the Private road transport industry and the Trucking services industry.

Chart 3.1. Policy and baseline paths of H&b expenditure ($m 2010 prices) and differences between the paths expressed as percent of baseline GDP

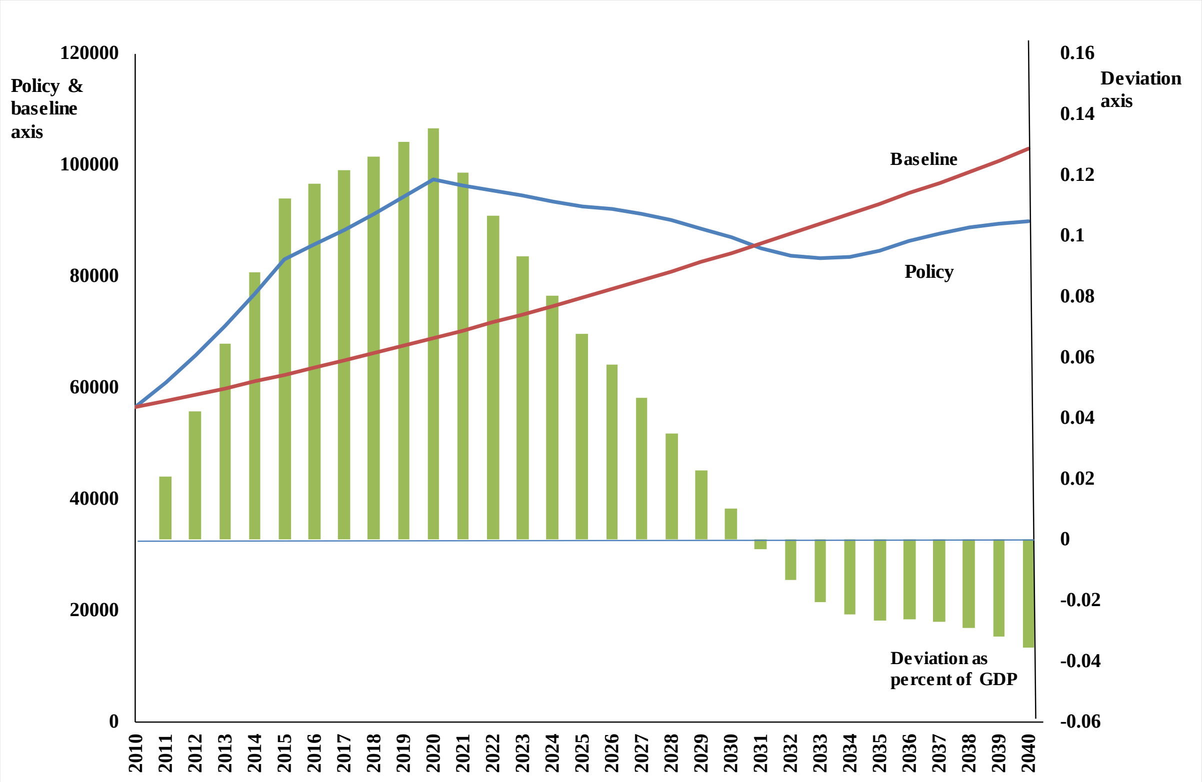


Chart 3.2. Maintenance cost savings ($m 2010 prices, increased investment - baseline)

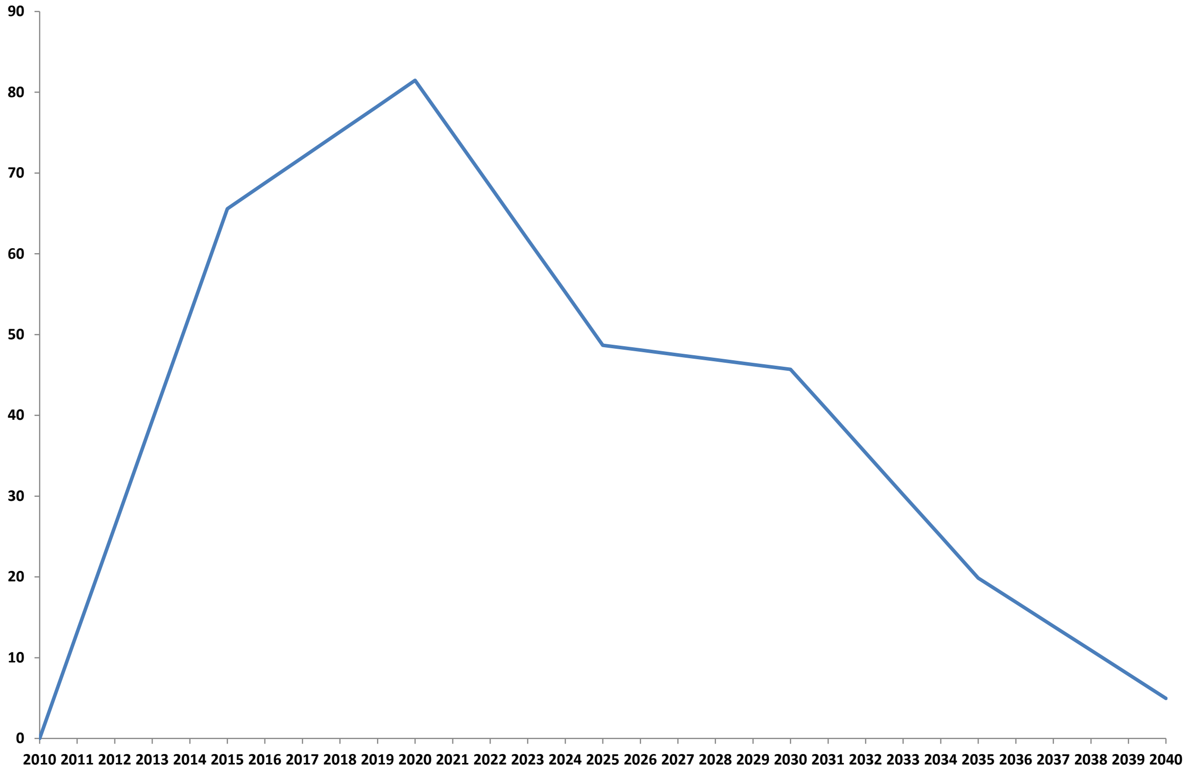
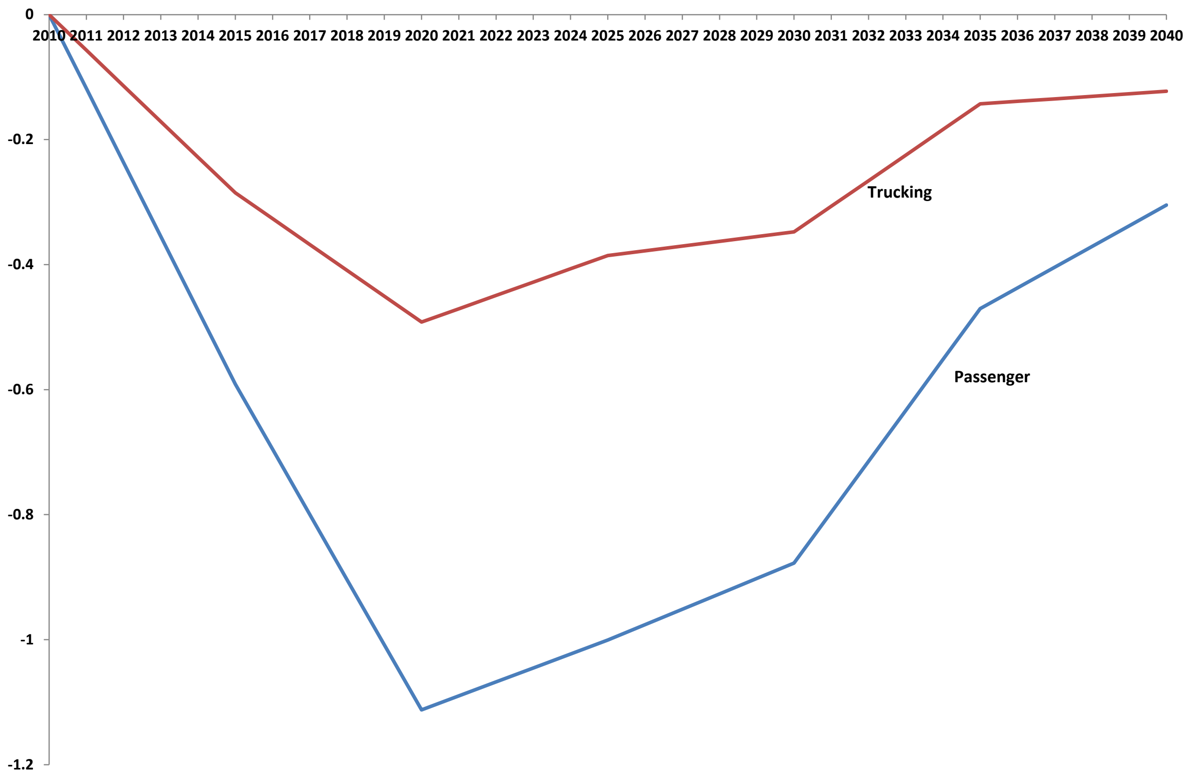


Chart 3.3. Percentage changes in vehicle operating costs per mile travelled



Fuel saving

As shown in Chart 3.4, the HERS results imply that additional highway investment increases fuel use per mile travelled. This is because of higher speeds. In USAGE-Hwy simulations we introduced the HERS results for passenger vehicles as shocks to fuel use per unit of output in the PRT industry and the HERS results for Trucking services as shocks to fuel use per unit of output in all other industries. Fuel is part of vehicle operating costs. To avoid double counting we did not allow the shocks to fuel costs to affect overall vehicle operating costs in the PRT and Trucking services industries. For these two industries, we allowed the introduction of shocks to fuel costs to affect the extent of saving of other inputs. In this way we accommodated the shocks to operating costs shown in Chart 3.3.

Medical costs and fatalities

Higher speeds and increased road use, both made possible by additional highway investment, cause increased accidents with increases in medical costs and fatalities. HERS results for these two effects for the expenditure scenario being investigated here are shown in Charts 3.5 and 3.6. As mentioned in section 2.6, the USAGE-Hwy measure of welfare excludes medical expenditures and includes a negative term for fatalities.

Charts 3.5 and 3.6 exhibit a rather jagged pattern. The HERS model produces results at 5 year intervals and the jagged patterns reflect the interpolation procedure used to convert the 5-year results into annual results. Fortunately the extra medical costs and fatalities are quite small and do not warrant the use of sophisticated smoothing procedures.

Chart 3.4. Percentage changes in fuel use per mile travelled

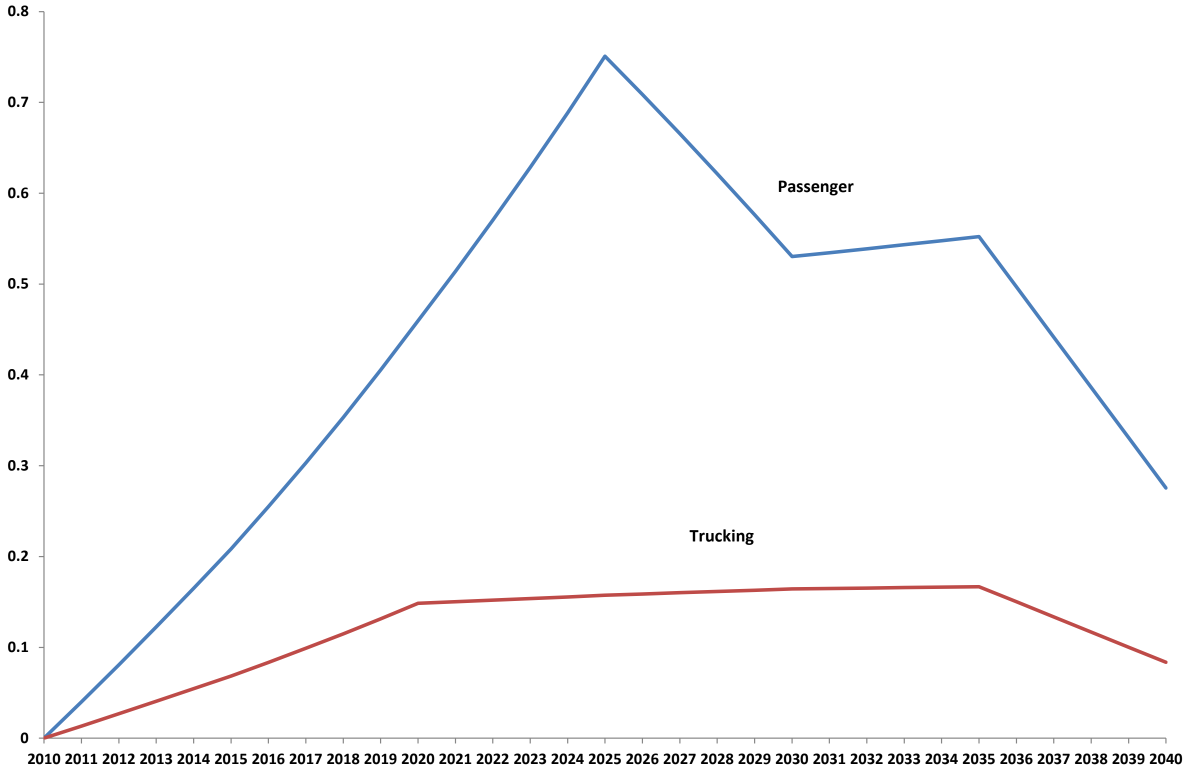


Chart 3.5. Extra medical costs associated with increased H&b expenditure expressed in $m (2010 prices) and a percent of baseline GDP

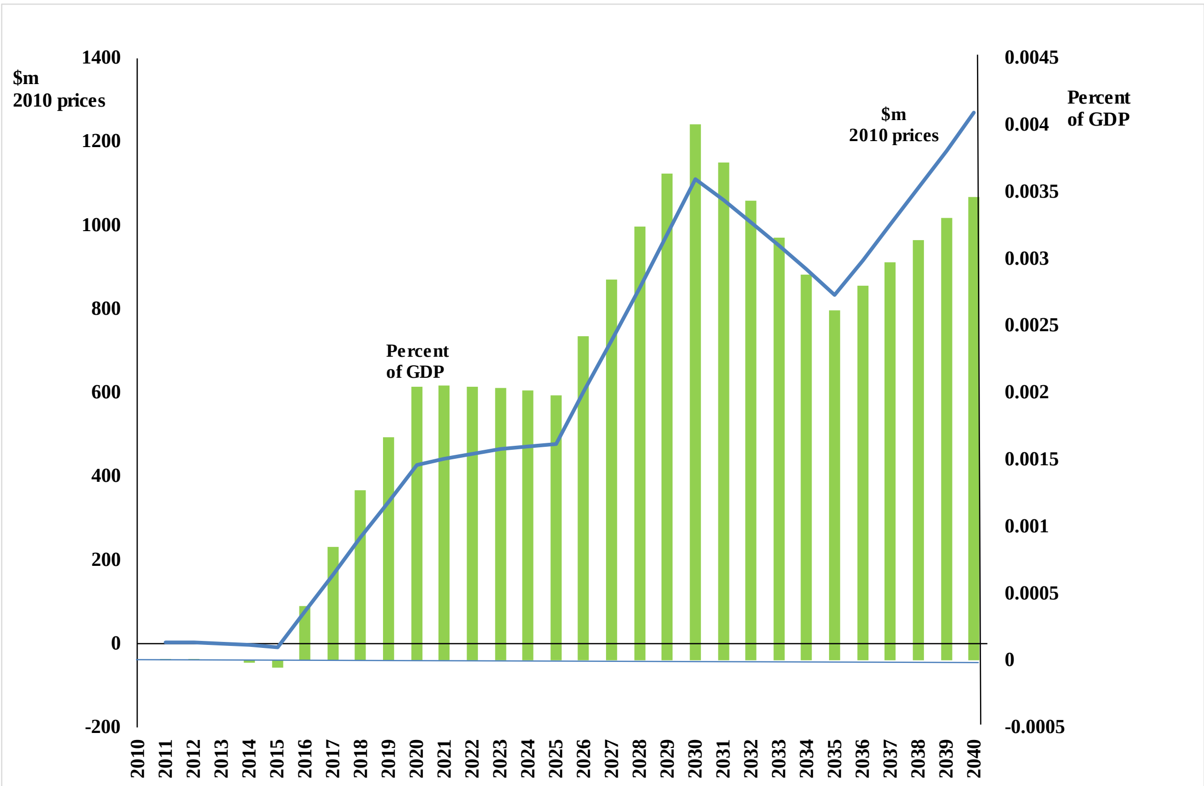
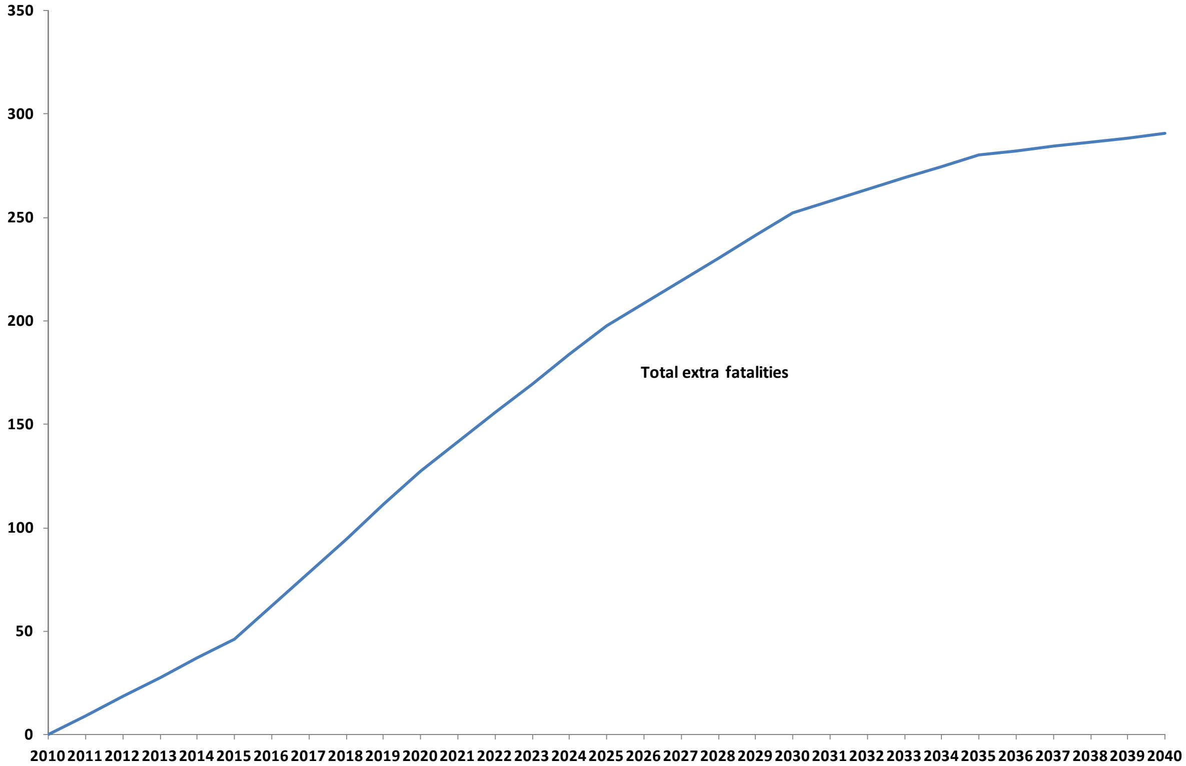


Chart 3.6. Extra fatalities associated with increased highway investment expenditure



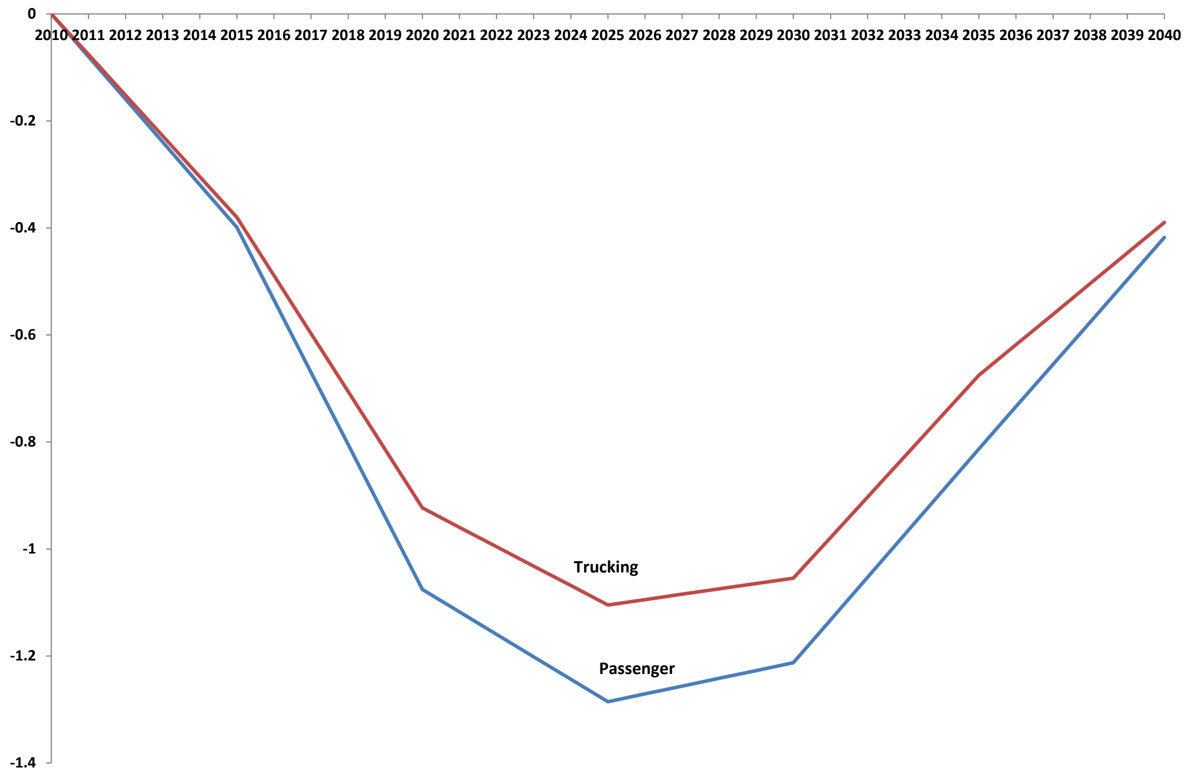
Saving of travel time

As shown in Chart 3.7, the HERS results imply that additional highway investment will reduce time per vehicle mile travelled (VMT) for both passenger vehicles and trucks. In USAGE-Hwy simulations, we introduce the HERS information in Chart 3.7 for passenger vehicles as percentage shocks to household time required per unit of sales of Private road transport (PRT) to Commuter transport (CT) and to Vacation transport (VT). This feeds into the rates of the phantom taxes on these sales (see the discussion of PRT in subsection 2.5). The HERS information in Chart 3.7 for trucking services was applied as percentage shocks to labor input per unit of output in the USAGE-Hwy Trucking services industry.

4. Simulating the effects of increased H&b spending: results from USAGE-Hwy under three financing options

Subsections 4.1 to 4.4 report results from three simulations (the central simulations) each with the same baseline and each with the policy shocks described in section 3. These simulations differ only in their financing assumptions. In the first simulation, the deviations in H&b expenditures are debt financed: the government does not change the rates of any taxes and simply allows the budget deficit to change. In the second simulation, the deviations are financed by a non-distortionary lump-sum tax: the government changes the rate of this tax so that the government deficit to GDP ratio follows the same path in the policy as it does in the baseline. In the third simulation, the deviations are financed by a petroleum tax applied at a uniform rate across all domestic sales of petroleum products for road use (excludes aviation fuels). As in the second simulation, the rate of the tax is varied so that the deficit/GDP ratio in the policy run follows its baseline path.

Chart 3.7. Percentage reductions in time per VMT associated with increased highway investment expenditure



There is considerable uncertainty about the relationship between travel time saving and labor supply. As described in subsection 2.5, for the central simulations we assumed that 10 per cent of saved vacation travel time and 25 per cent of saved commuter travel time are translated into increased labor supply. Subsection 4.5 reports sensitivity analysis in which all saved travel time is devoted to leisure.

4.1. Overview of the main results: employment and welfare in the central simulations

Chart 4.1 shows the effects of increased H&b expenditure on aggregate employment in the central simulations. With deficit financing, the policy strongly stimulates employment in the early years. The policy-induced increase in employment peaks at 0.10 per cent in 2020 (about 150 thousand jobs in today's terms). Eventually the employment deviation turns around. In 2040 employment in the policy run is only 0.01 per cent above its baseline level. With non-distortionary-tax financing (lump-sum tax), the employment deviation path has a similar shape to that under deficit financing. However the employment effects are less favourable in the early years with lump-sum taxation than with deficit financing, but more favourable in later years. With the H&b expenditure financed by a petroleum tax, the employment deviation is subdued in the early years, strongly positive in the middle years and turns slightly negative by 2040.

Chart 4.2 shows the effects of increased H&b expenditure on aggregate welfare measured according to equation (2.2). With deficit financing, welfare increases strongly in the early years reaching a deviation of 0.27 per cent of the baseline level of consumption in 2022 (about \$27.4b in 2010 prices). The deviations then decline steadily to close to zero in 2040. With the H&b expenditures financed by a lump-sum tax, the welfare deviations are approximately zero until 2015. Beyond 2015 the welfare deviations increase steadily until

Chart 4.1. Aggregate Employment
(percentage deviations from baseline)

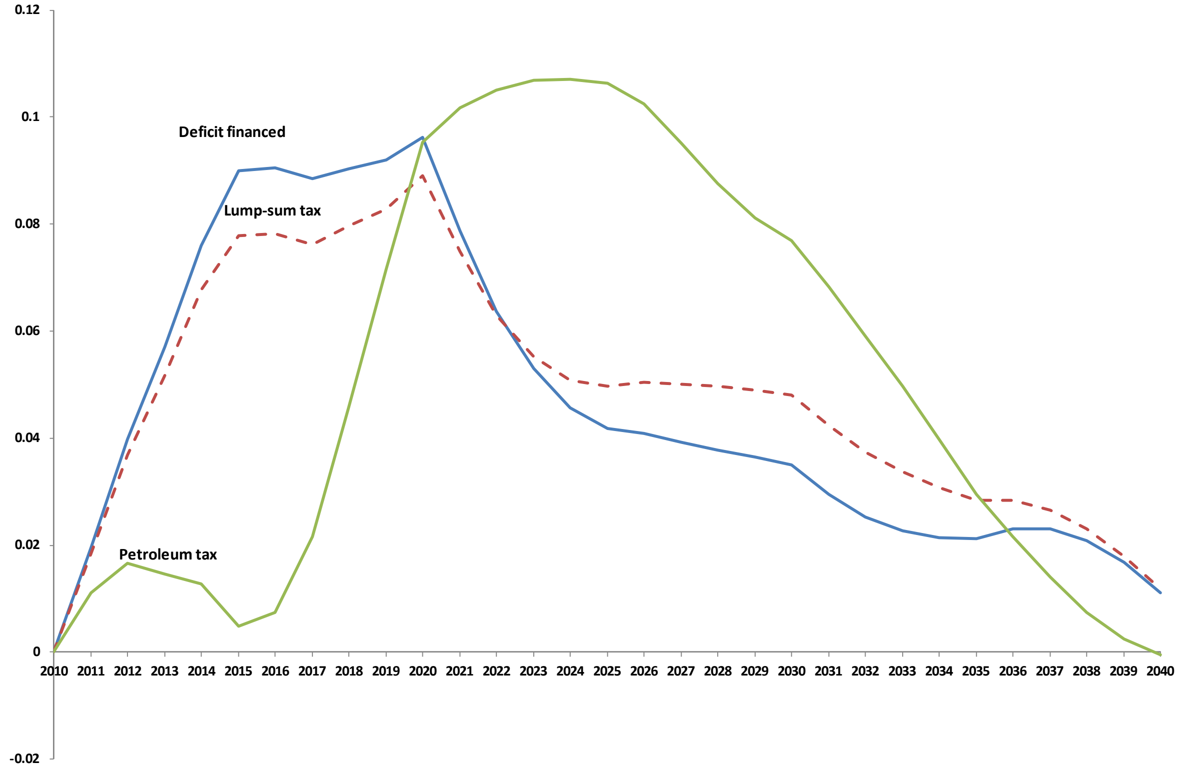
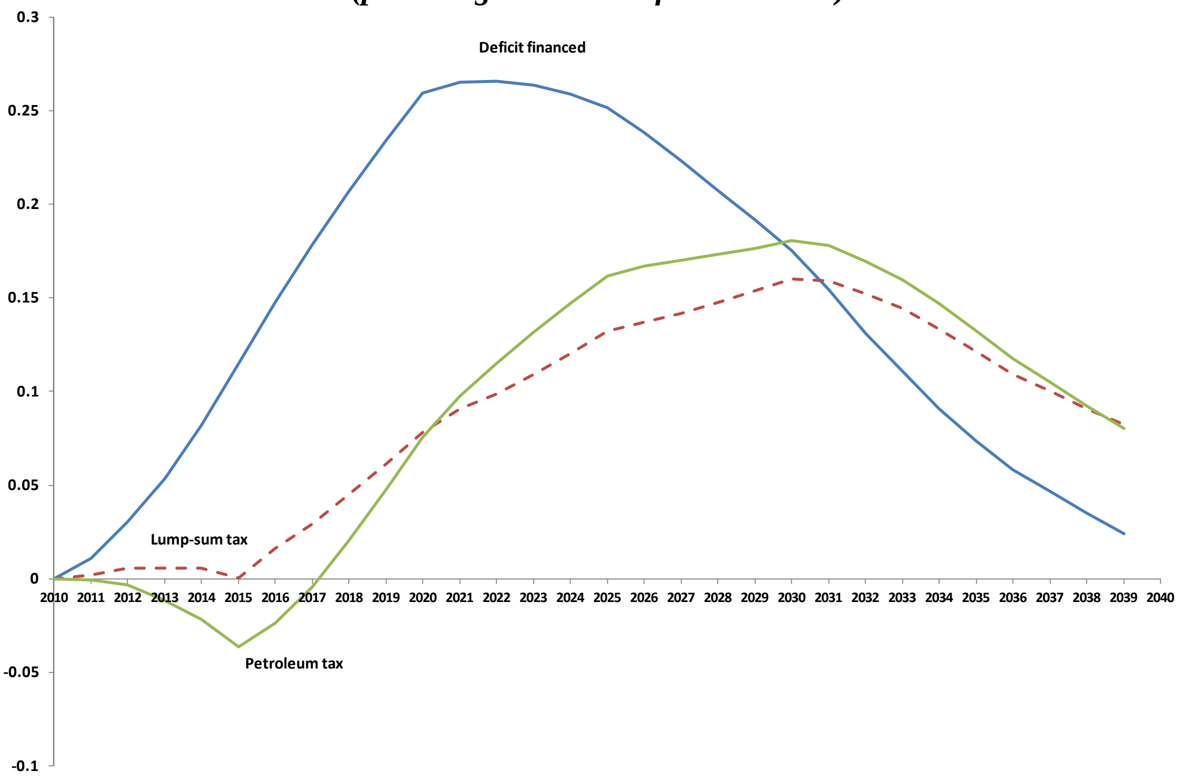


Chart 4.2. Aggregate Welfare
(percentage deviations from baseline)



2031 and then decline for the rest of the simulation period. H&b expenditures financed by a petroleum tax are welfare-reducing in the short run but produce a welfare deviation path beyond 2019 that is similar to the deviation path in the lump-sum simulation.

The 30 years of welfare deviation results in Chart 4.2 for deficit financing average 0.151. The average deviations in the lump-sum and petroleum tax simulations are 0.091 and 0.095. If we discount each year's deviation back to 2010 with a 4 per cent discount rate, then the three averages are 0.089, 0.045 and 0.044.

Subsections 4.2 to 4.4 explain the employment and welfare results in detail and cover several other macro variables.

4.2. Deficit financing

Chart 4.3 gives labor-market results for the effects of increased H&b expenditure under deficit financing. To understand these results, a useful back-of-the-envelope (BOTE) equation is

$$W = P_{gdp} * A * F_{\ell}(K/L) \tag{4.1}$$

where

W is the average wage rate;

P_{gdp} is the price deflator for GDP and represents the price of a typical unit of U.S. output;

K is aggregate capital;

L is total employment;

A is a technology variable representing total factor productivity; and

$A * F_{\ell}(K/L)$ is the marginal product of labor derived by differentiating the constant-returns-to-scale production function Y = A*F(K,L) with respect to L.

Equation (4.1) is a stylized version of the assumption built into CGE models such as USAGE that employers hire labor up to the point at which the wage rate equals the value of the marginal product of labor.

Dividing both sides of (4.1) by the price deflator for consumption (P_c) gives

$$\frac{W}{P_c} = \frac{P_{gdp}}{P_c} * A * F_{\ell}(K/L) \tag{4.2}$$

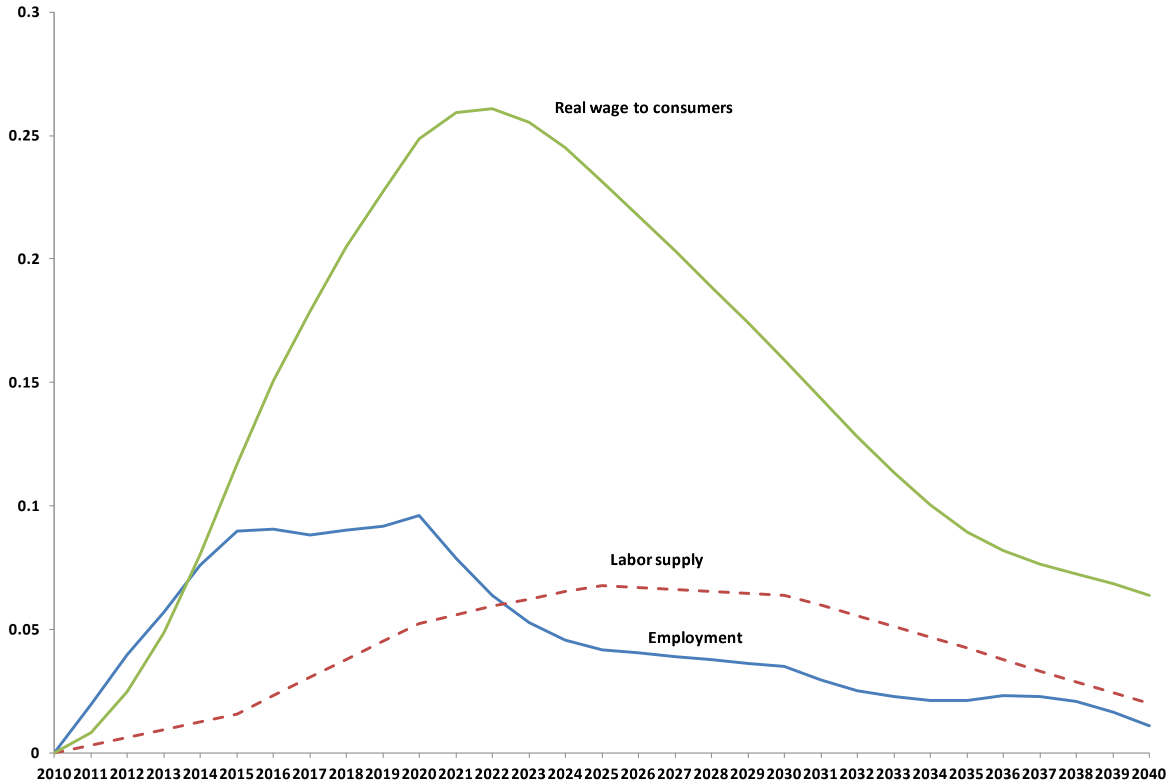
The LHS of (4.2) is the real wage rate from the point of view of consumers.

In USAGE-Hwy policy runs we assume that the consumer real wage rate adjusts in a sticky fashion to gaps between demand and supply for labor. In the very short run it is reasonable to think of W/P_c as being fixed. On the right hand side of (4.2), the H&b investment program causes an increase in A through the saving of time and intermediate inputs in the Trucking services and PRT industries. The program also generates an increase in P_{gdp}/P_c for two reasons, which can be understood via the identity:

$$\frac{P_{gdp}}{P_c} = \frac{P_{gdp}}{P_{gne}} * \frac{P_{gne}}{P_c} \tag{4.3}$$

where P_{gne} is the price of gross national expenditure (the price of goods and services absorbed in the U.S.). The first reason is that deficit-financed expenditures (which lead to an increase in demand for goods and services in the U.S. relative to U.S. output) cause real appreciation, that is an increase in the U.S. price level relative to the price levels in U.S. trading partners expressed in U.S. dollars via the exchange rate. Real appreciation causes a reduction in U.S.

Chart 4.3. Labor market variables: H&b expenditures financed by deficit spending (percentage deviations from baseline)



exports and an increase in imports, with a consequent improvement in the terms of trade (the price of exports relative to the price of imports).[2] These effects can be seen in Chart 4.4. An improvement in the terms of trade raises P_{gdp}/ P_{gne}. This is because the main difference between P_{gdp} and P_{gne} is that P_{gdp} includes export prices but not import prices, while P_{gne} includes import prices but not export prices. The second and reinforcing cause of the increase in P_{gdp}/P_c in the present simulation is that within gross national expenditure, extra H&b expenditures increase the price of construction services and consequently the price of investment expenditures relative to the price of consumer goods. Hence, P_{gne}/P_c increases.

With sticky adjustment in W/P_c and increases in A and P_{gdp}/P_c, preservation of equation (4.2) requires a reduction in $F_\ell(K/L)$ which in turn requires a reduction in K/L. In the short run, K can be considered fixed. Thus, as shown in Chart 4.3, employment (L) initially increases.

Going beyond equation (4.2), there is another factor which contributes to the H&b-induced increase in employment in the results for the early years in Chart 4.3. H&b expenditures are highly labor intensive. Thus, at any given real wage, a switch in demand from exports to H&b is employment-creating.

As H&b expenditures increase up to 2020 (Chart 3.1), the employment deviation in Chart 4.3 also increases (although only gradually after 2015 when the rate of growth of H&b expenditures slows). Labor supply also increases in the early years: the deviation path of labor supply is determined largely by the path of time saving in the use of passenger vehicles shown in Chart 3.7. However, the initial percentage increases in labor demand (employment)

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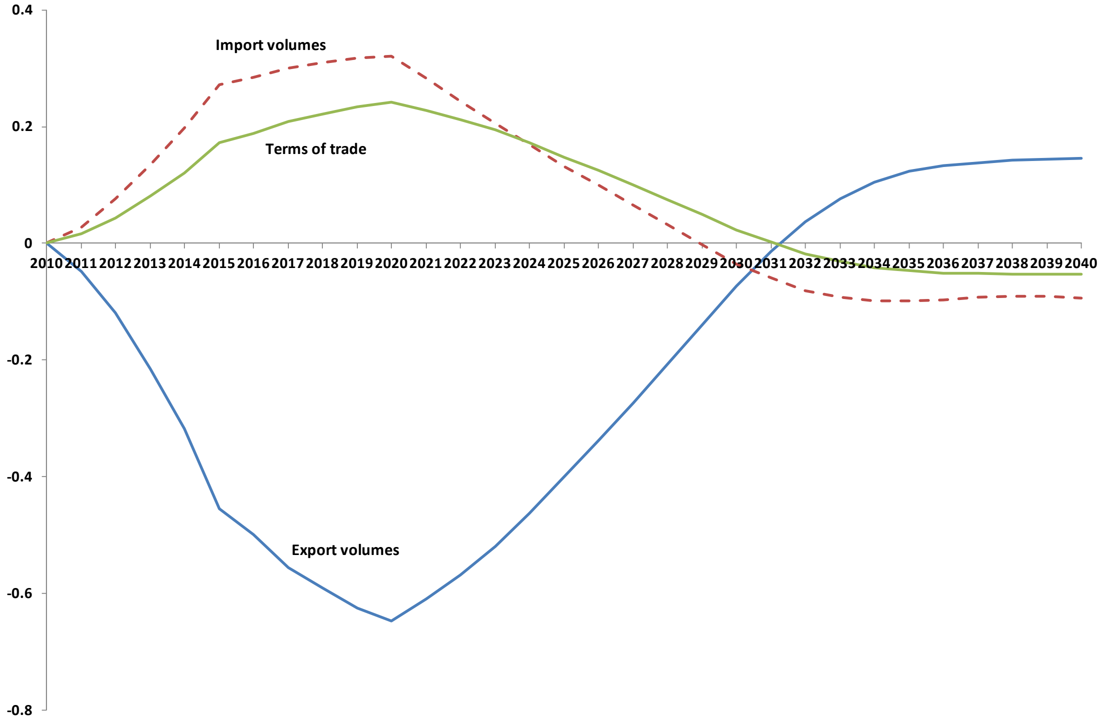
[2] We assume that foreign-demand curves for U.S. exports slope down but that foreign supply curves of imports to the U.S. are flat.

Chart 4.4. Trade variables: H&b expenditures financed by deficit spending (percentage deviations from baseline)



exceed those in labor supply. Under our sticky-wage-adjustment mechanism, if a policy increases the ratio of employment to labor supply relative to its baseline value, then real consumer wage rates increase relative to their baseline value. With the slowdown beyond 2015 in H&b expenditures and the increase in real wages, the employment deviations eventually decline. By 2022 the deviation in employment falls below the deviation in labor supply causing the deviation in the real consumer wage to decline. By 2040 the deviations in labor supply and employment are approximately converged and the deviation in the real wage rate is approximately stabilized. Although by 2040 much of the cost and time savings associated with improved H&b infrastructure have been exhausted, there are still sufficient savings (Charts 3.3 and 3.7) to allow positive deviations in real wages, labor supply and employment.

Chart 4.5 shows deviations in GDP and contributing components. It can be understood via the BOTE equation

$$y = a + S_L * \ell + S_K * k \qquad (4.4)$$

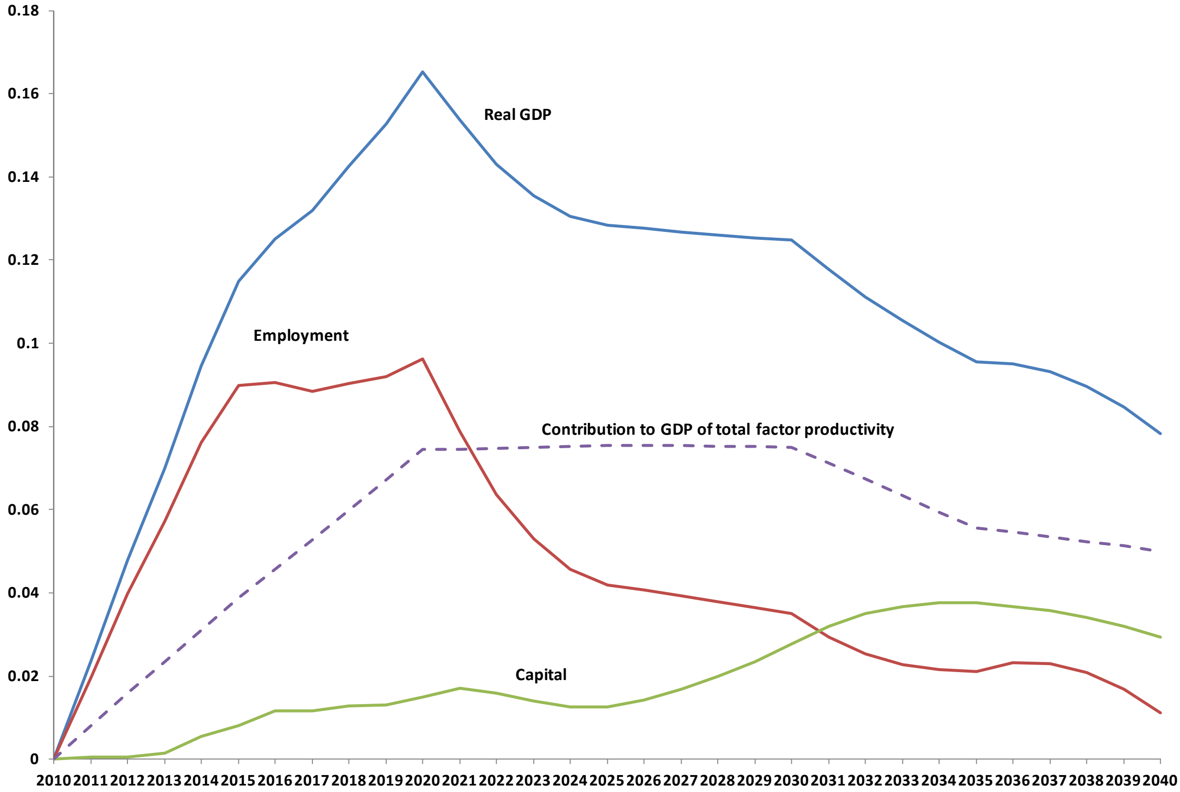
where

y is the percentage deviation in GDP;
a is the percentage deviation in total factor productivity;
k and ℓ are the percentage deviation in aggregate capital and employment; and
S_K and S_L are the shares of capital and labor in US GDP, approximately 0.35 and 0.65.

As can be seen from the chart, the GDP deviation peaks at 0.17 per cent in 2020, about \$24b in the U.S. economy of 2010. Most of this deviation is contributed by total factor productivity and employment. Capital also makes a positive contribution.

A BOTE equation for understanding the positive deviations in capital is

Chart 4.5. GDP and factor inputs: H&b expenditures financed by deficit spending (percentage deviations from baseline)



$$\frac{Q}{P_i} = \frac{P_{gdp}}{P_i} * A * F_k(K/L) \tag{4.5}$$

where

Q is the average rental rate on units of capital;

P_i is the price deflator for capital goods or investment; and

$A * F_k(K/L)$ is the marginal product of capital.

This equation is the capital-market counterpart of (4.2). It equates the real rental on capital with the value of the marginal product of capital deflated by the investment price index.

As explained already, the H&b expenditure program initially increases A and decreases K/L. Both these movements increase the right hand side of (4.5). P_{gdp}/P_i is also affected by the H&b expenditure program. However, the A and K/L effects dominate ensuring that Q/P_i exhibits positive deviations throughout most of the simulation period. Increases in Q/P_i stimulate investment: Q/P_i is closely related to the rate of return on capital. With higher investment the capital stock shows positive deviations in Chart 4.5 throughout the simulation period.

To conclude this subsection we return to the welfare deviations shown for deficit financing in Chart 4.2. The welfare deviations are positive throughout the simulation period. The peak deviation, which occurs in 2020, coincides with the peak GDP deviation and the peak deviations in employment and total factor productivity. Although the additional H&b expenditure is deficit financed, it is not free. As can be seen in Chart 4.4, with deficit financing, the H&b program causes negative deviations in the balance of trade for most of the simulation period. This leads to higher net foreign liabilities and higher interest and dividend payments to foreigners with a consequent reduction in income available to U.S. households.

This effect combined with the gradual elimination of time saving (Chart 3.7) and saving of vehicle operating costs (Chart 3.3) explains why the welfare deviation under deficit financing declines towards zero in the second half of the simulation period.

4.3. Lump-sum-tax financing

With tax financing, the resources required for H&b infrastructure expenditures are diverted largely from consumption rather than from exports. Consequently in the early years (see Chart 4.2), the welfare deviations with lump-sum taxation are close to zero.

However, the macroeconomic effects of H&b expenditures are favorable, see Charts 4.6 and 4.8. Employment is initially stimulated by the labor intensity of H&b expenditures. In terms of equation (4.2), employment is also stimulated by the increase in A (time and cost saving in Trucking and PRT). Further employment stimulation is provided by an increase in P_{gdp}/P_c, which can be explained in two steps. First, the shift in GNE in favor of H&b spending relative to consumption causes the price of investment (P_i) to increase relative to the price of consumption (P_c), which means that P_{gne}/P_c increases. Second, as we will see shortly, H&b spending, even with tax financing, causes a short-run improvement in the terms of trade, raising P_{gdp}/P_{gne}. Thus, via (4.3) we see that P_{gdp}/P_c increases.

While the short-run macroeconomic effects of H&b expenditure are favorable under lump-sum-taxation, they are not as favorable as under deficit financing. The employment deviation under lump-sum financing peaks in 2020 at 0.089 per cent rather than 0.096 per cent, and the GDP deviation peaks at 0.15 per cent rather than 0.17 per cent (compare Charts 4.8 and 4.5). These less favorable macroeconomic effects can be explained via the terms of trade which improves less with tax financing than with deficit financing: as already mentioned, tax financing is less damaging to exports than deficit financing (compare Charts 4.7 and 4.4). One final question remains: why do exports decline at all under tax financing?

An equation that helps us understand this result is:

$$Y = C + I + G + X - M \qquad (4.6)$$

where

Y is real GDP; and

C, I, G, X and M are the real expenditure aggregates: private consumption, investment, public expenditure, exports and imports.

H&b expenditures increase G. Despite these expenditures being completely financed by the lump-sum tax, there is sufficient stimulation of C and I to stimulate GNE (= C + I + G) relative to GDP. Consequently, X – M must decline via a real appreciation causing X to fall, with a consequent improvement in the terms of trade. The stimulating factor for C is the decline in P_c relative to P_{gdp} and the stimulating factor for I is the initial increase in employment.

In the later years of the simulation period, the welfare deviations in Chart 4.2 under lump-sum taxation are more positive than those under deficit financing. This is because the balance-of-trade deficits in the early years are smaller under lump-sum taxation. Consequently net foreign liabilities and interest/dividend payments are smaller in the later years for tax-financed H&b expenditures.

Chart4.6. Labor market variables: H&b expenditures financed by a lump-sum tax (percentage deviations from baseline)

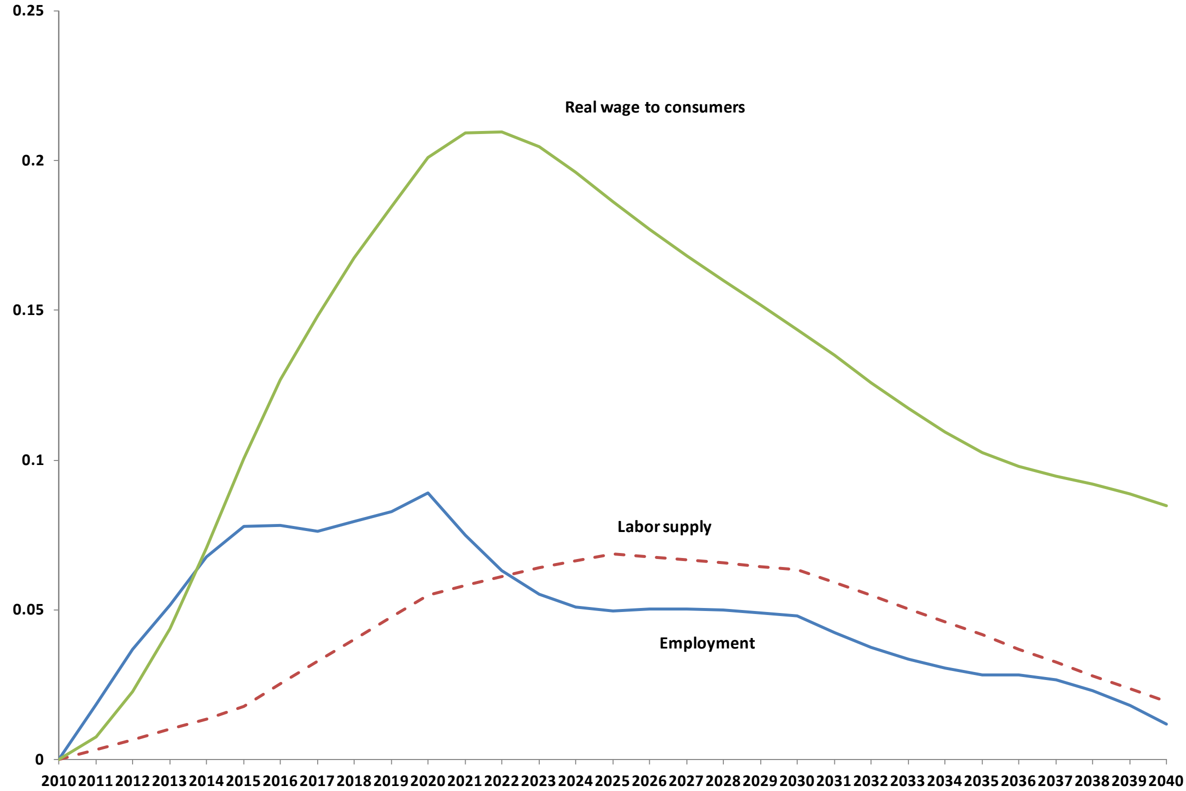


Chart 4.7. Trade variables: H&b expenditures financed by a lump-sum tax (percentage deviations from baseline)

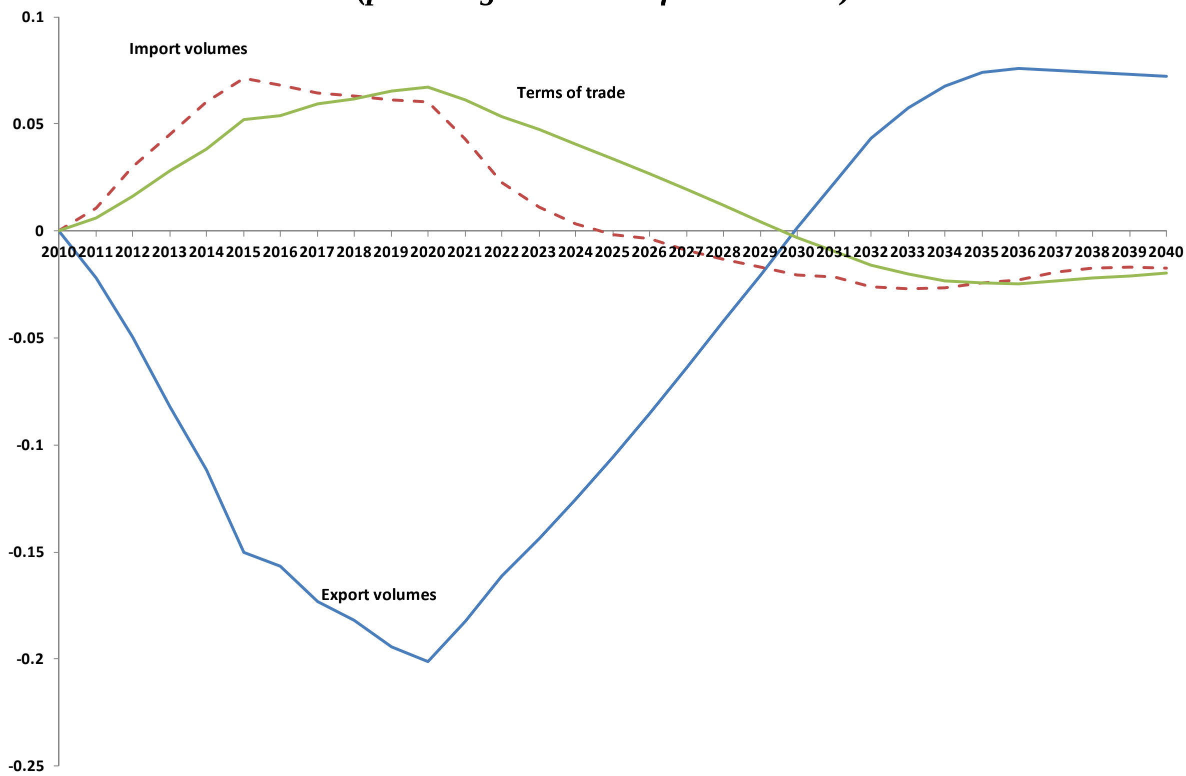
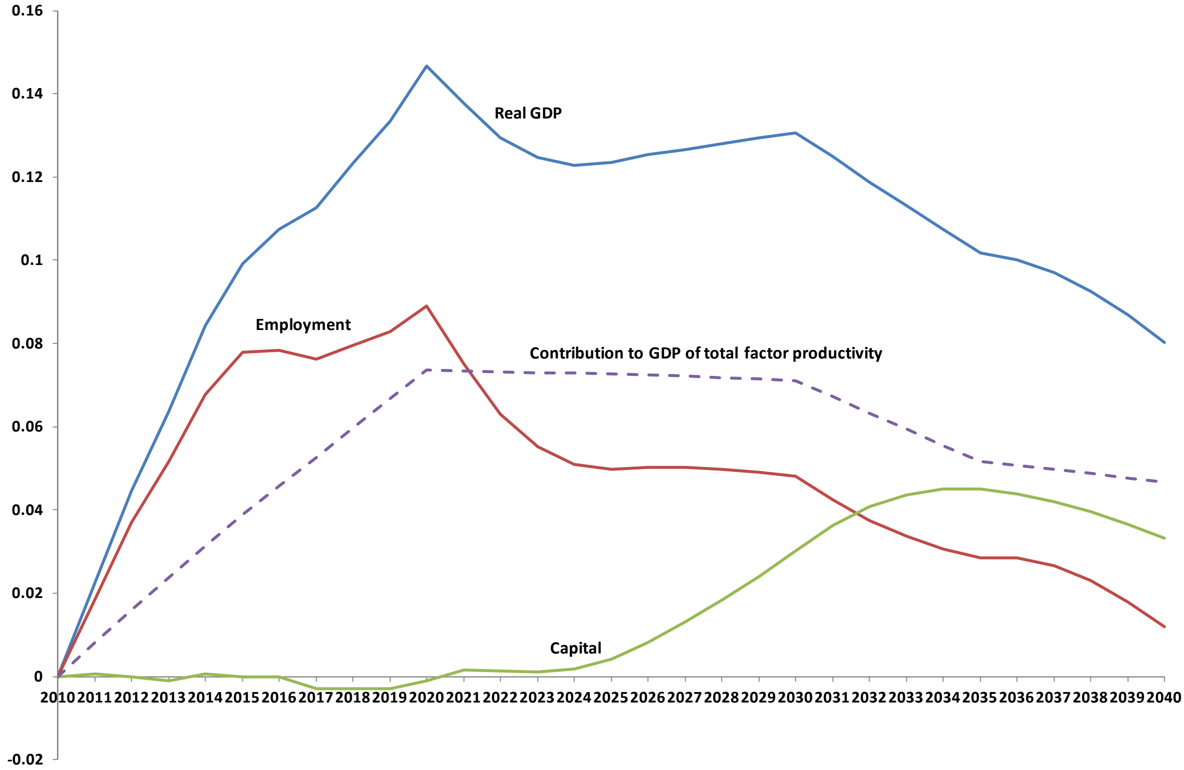


Chart 4.8. GDP and factor inputs: H&b expenditures financed by a lump-sum tax (percentage deviations from baseline)



4.4. *Petroleum-tax financing*

In the years up to 2016, the employment effects of H&b spending under petroleum-tax financing are barely positive (see Chart 4.1 or 4.9). To understand this result we need a refined version of equation (4.2):

$$\frac{W}{P_c} = \frac{P_{gdp}}{P_c} * (1 - T) * A * F_{\ell}(K/L) \tag{4.7}$$

In (4.7), T is the average rate of indirect tax. By introducing T, we recognize that in valuing the marginal product of labor to employers we should deduct indirect taxes from the price of output (P_{gdp}).

In terms of (4.7), the introduction of a petroleum tax to finance H&b expenditures is equivalent to an increase in T. The increase in T [i.e. the decrease in (1 - T)] causes $F_{\ell}(K/L)$ to be higher in the short run under petroleum-tax financing than under either lump-sum or deficit financing. With K moving slowly, a higher value of $F_{\ell}(K/L)$ explains the relatively muted short-run employment response to H&b expenditures in the petroleum-tax simulation.

The increase in A and the labor intensity of H&b expenditure allow employment to increase in the early years of the petroleum-tax simulation, despite the T effect. However the T effect is sufficient to turn the investment and capital deviations negative in the early simulation years, see Chart 4.11.[3] Nevertheless, GDP increases: in terms of equation (4.4) the increases in A and L outweigh the decreases in K.

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[3] Equation (4.5) can be revised to include the T effect: $\frac{Q}{P_i} = \frac{P_{gdp}}{P_i} * (1 - T) * A * F_k(K/L)$.

Chart 4.9. Labor market variables: H&b expenditures financed by a petroleum tax (percentage deviations from baseline)

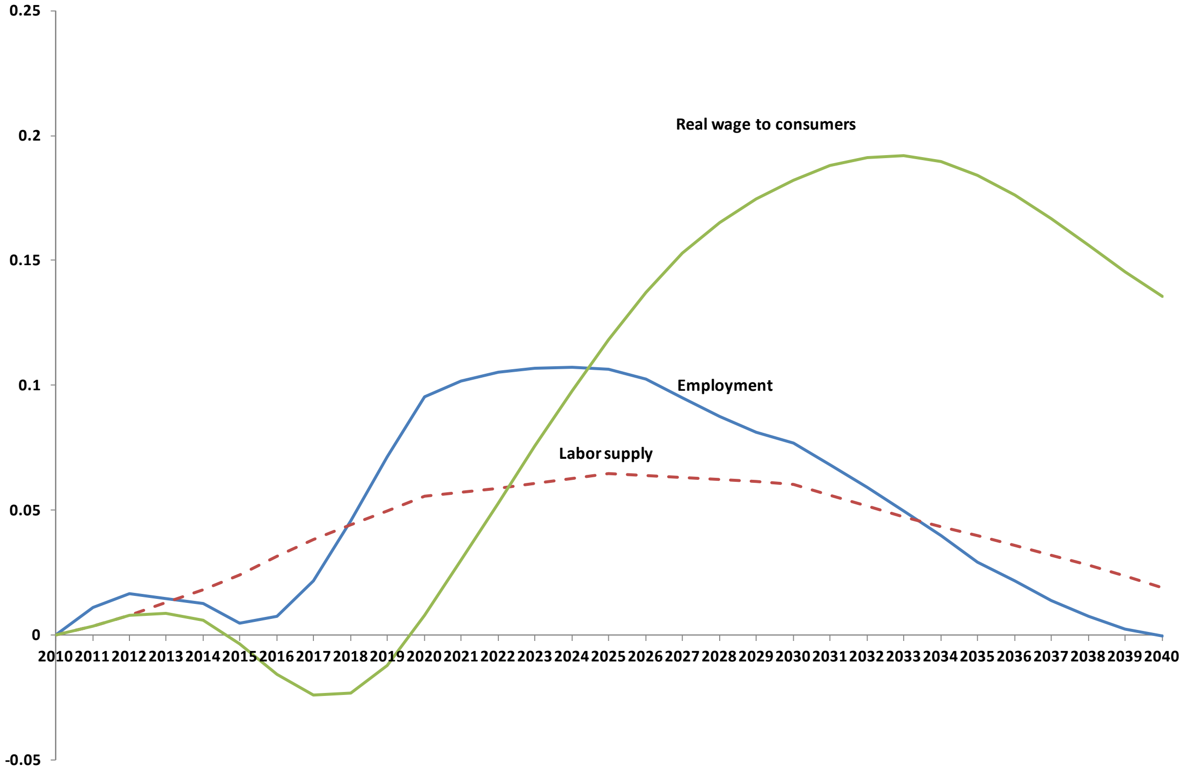


Chart 4.10. Trade variables: H&b expenditures financed by a petroleum tax (percentage deviations from baseline)

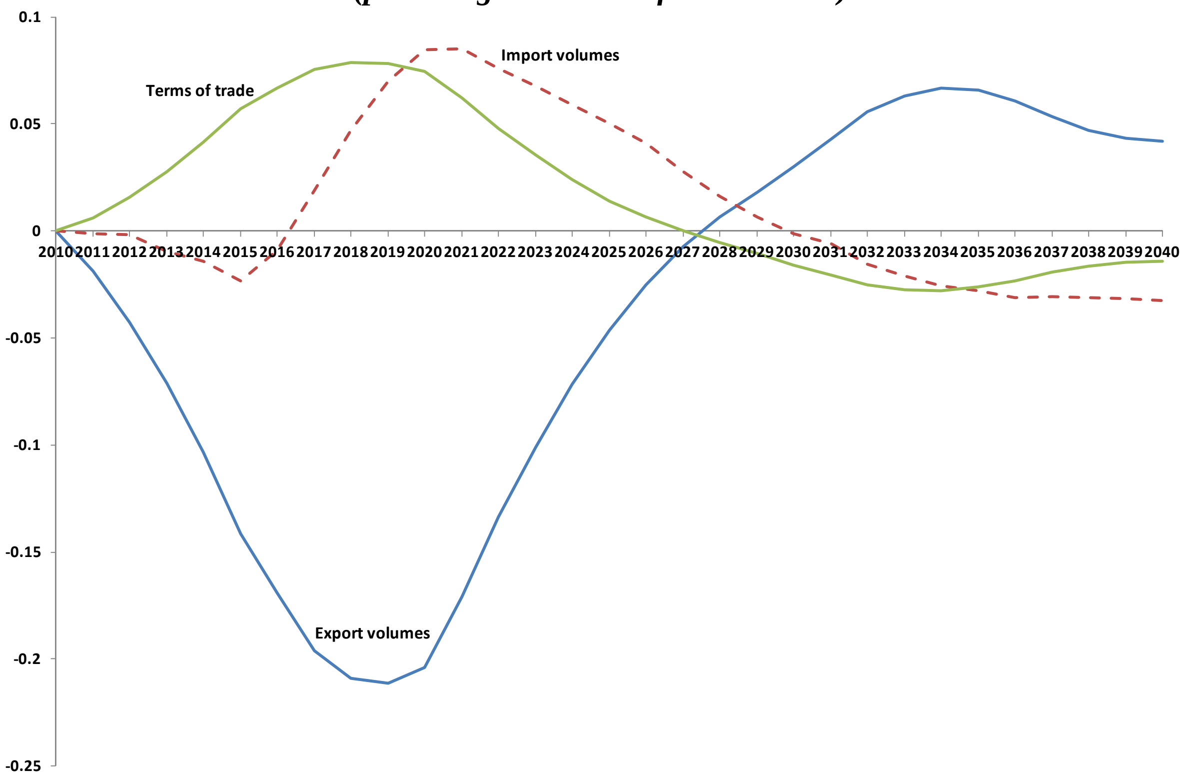
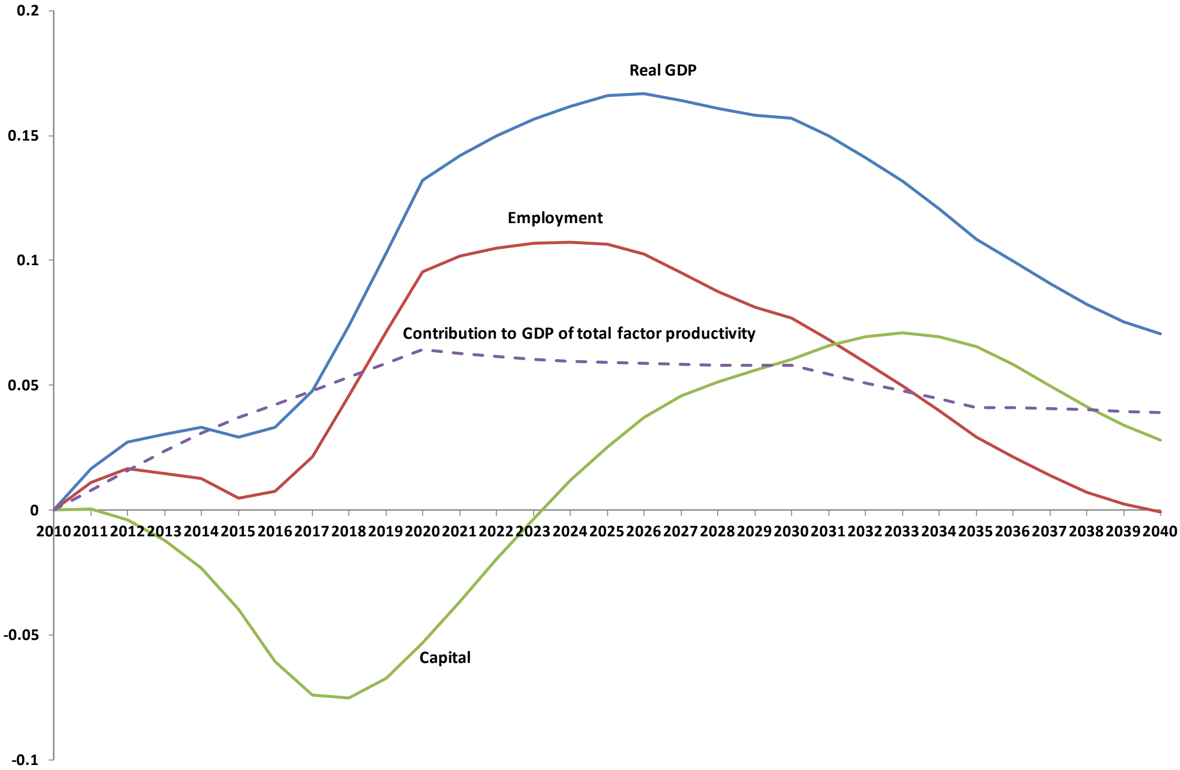


Chart 4.11. GDP and factor inputs: H&b expenditures financed by a petroleum tax (percentage deviations from baseline)



Between 2016 and 2020, the employment deviation under petroleum-tax financing grows quickly (see Chart 4.9). The main reason is that rather than growing rapidly as it did between 2011 and 2016, the rate of petroleum tax falls. This is caused by the slowdown in the growth of H&b expenditures (Chart 3.1) combined with the stimulation in the collection of other taxes associated with the elevation of GDP. These factors reduce the rate of petroleum taxes required to finance H&b expenditures.

Eventually the elevation of employment relative to labor supply (Chart 4.9) causes wage rates to rise and employment growth to slow and then fall. In the long run (beyond 2034), the employment deviation drops below the labor supply deviation causing the wage rate deviation path to turn down. If we extended the simulation period, then the employment deviation would converge to the labor supply deviation after some damped oscillations.

Relative to the lump-sum case, the welfare effects under petroleum-tax financing are weak in the short run and then more favourable after 2020 (Chart 4.2). The relatively weak short-run welfare effects for petroleum-tax financing reflect the relatively weak short-run employment effects. Comparing Charts 4.10 and 4.7 shows that the short-run effects of the H&b expenditure program are less negative for the balance of trade under petroleum-tax financing than under lump-sum-tax financing. This explains why, in the longer term, petroleum-tax financing gives more positive welfare effects than lump-sum-tax financing.

There is nothing in this explanation of the petroleum-tax results that is specific to petroleum. Results similar to those in Charts 4.9 to 4.11 would be obtained in a simulation in which H&b expenditures are financed by a general tax on consumption.

4.5. Sensitivity simulations: the welfare effects of H&b expenditures when time saving does not affect labor supply

As we saw in section 2, extra H&b expenditure reduces passenger travel time. Recall that in our three central simulations, described in subsections 4.1 to 4.4, we assumed that 25 per cent of travel-time saved in commuter travel (CT) and 10 per cent saved in vacation travel (VT) is converted into extra work. In this subsection we compare welfare results from three sensitivity simulations in which none of the passenger travel-time saving is converted into extra work with those from the three central simulations.

In all our simulations, an extra hour of work reduces leisure by an hour. An extra hour of work generates income worth the average wage whereas, under our assumptions, the loss of an hour of leisure costs only 0.4348 times the average wage. Consequently our prior expectation was that the simulated welfare effects of H&b expenditures would be lowered when we rule out the possibility of converting travel-time saving (extra leisure) into extra consumption via extra work. This expectation is confirmed in Chart 4.12 which shows the differences between welfare effects in the three sensitivity simulations and the corresponding central simulations. But why are the welfare differences so small under deficit financing?

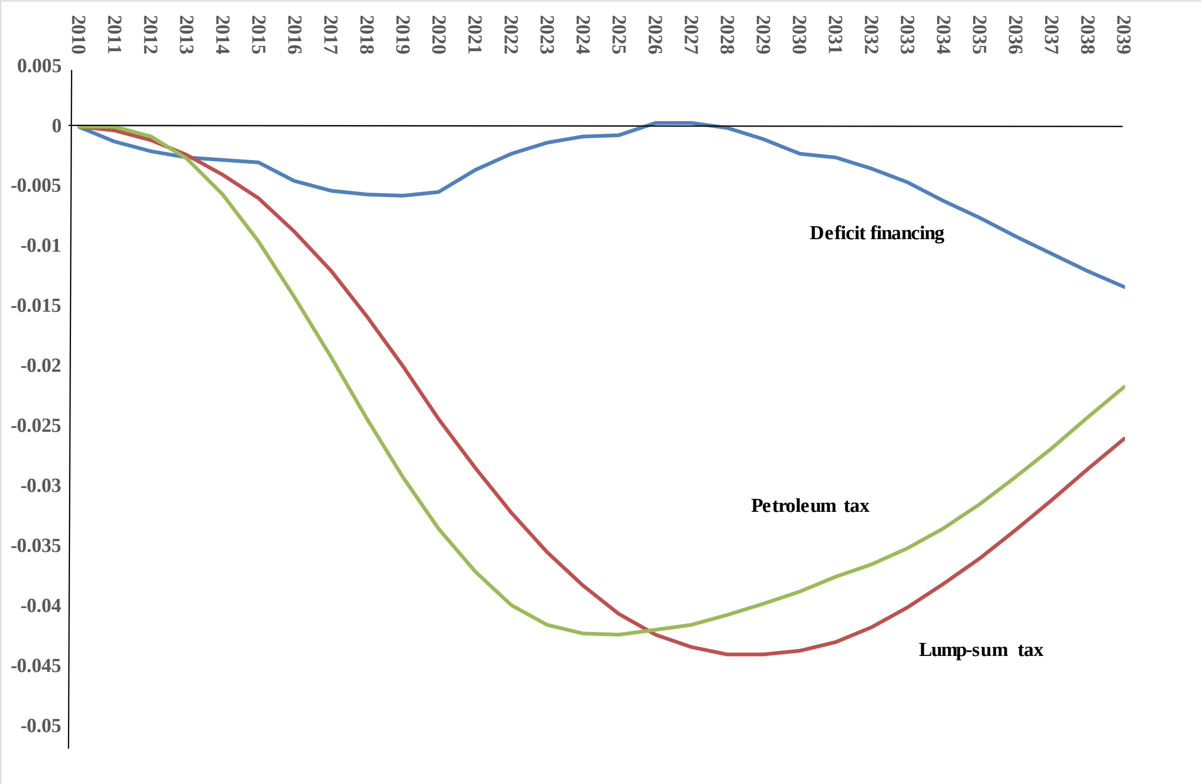
In the sensitivity simulations, ruling out the labor supply boost from H&b expenditures causes employment to follow lower paths than in the central simulations. This causes social security payments and other government benefits to households in the sensitivity simulations to be higher than in the central simulations. In the sensitivity simulations with tax financing, these extra government benefits do not stimulate consumption. Instead, they cause the lump-sum or petroleum tax rates to be higher than in the corresponding central simulations so that the public-sector deficit to GDP ratio can stay on its baseline path. In the sensitivity simulation with deficit financing, there is no requirement to keep the public-sector deficit to GDP ratio on its baseline path. Consequently, extra social security payments stimulate consumption in the sensitivity simulation with deficit financing. This stimulation is sufficiently welfare-enhancing to largely offset the welfare-damping effect of ruling out the time-saving/labor-supply link. Only towards the end of the simulation period is there a noticeable difference between the sensitivity and central simulations in their welfare results under deficit financing. In the sensitivity simulation under deficit financing, there is a more rapid build-up of net foreign liabilities than in the corresponding central simulation. Eventually, the extra interest and dividend payments to foreigners start to exert a significant negative influence on household income and consumption.

5. Concluding remarks

HERS is a highway model for the U.S. incorporating detailed technical information provided by transport engineers. It gives results for many variables which are normally outside the scope of economic models. These include: time use, fuel use and other operating costs in trucking and private road transport; highway infrastructure and maintenance costs; medical expenditures associated with the use of highways; and highway fatalities.

For this paper, we have modified the economic model USAGE so that it can absorb information on these HERS variables. To do this we added several new industries/commodities: Highway and bridge construction; Street repairs; Private road transport; Vacation transport; Commuter transport; and Household car repairs. We have allowed for the cost of time in using various transport services and created a welfare function which recognizes not only household consumption but also leisure and road fatalities.

Chart 4.12. Differences in welfare effects between sensitivity (no labor supply increases) and central simulations (with labor supply increases) (percentage point differences)



In this way we have created USAGE-Hwy as a tool for translating results from HERS into outcomes for economic variables such as aggregate welfare, employment, exports, imports, private consumption, investment, government consumption, net foreign liabilities, average wage rates, labor supply and the public sector deficit. We see this as potentially important for bringing the technical/engineering analyses that underlie HERS into the economic domain and thereby facilitating the use of HERS results in policy discussions of expenditure priorities.

The Trump administration is emphasizing the importance of public infrastructure for the U.S. economy. To illustrate how HERS and USAGE-Hwy can be used together to analyse a specific infrastructure policy, we conducted simulations on the effects of a program of additional expenditure on highways and bridges. The credibility of these simulations is enhanced by incorporating engineering detail. The simulations add value to purely engineering analyses by providing economic insights on important policy dimensions such as effects on employment, welfare and trade under different financing arrangements.

Incorporating engineering information not only improves the quality of economic analyses, but also facilitates communication with naturally sceptical specialists in technical areas. Economists need to show that they are taking on board technical realities even when some of these realities may be of rather minor macroeconomic importance. For CGE modellers communication with other economists and policy advisors is also a challenge. How can we make our results understandable to people who cannot spend many hours working through model documentation? In section 4 we showed how this challenge can be met by back-of-the-envelope (BOTE) equations and calculations that expose the main mechanisms underlying results from complex CGE simulations.

References

Adams, P.D. and B.R. Parmenter (2013), "CGE modeling of environmental issues in Australia", chapter 11, pp. 553-657 in P.B. Dixon and D.W. Jorgenson (editors) *Handbook of CGE Modeling*, Elsevier, Amsterdam.

Dixon, P.B. and M.T. Rimmer (2002), *Dynamic General Equilibrium Modelling for Forecasting and Policy: a practical guide and documentation of MONASH*, North Holland Publishing Company, Amsterdam.

Dixon, P.B. and M. Rimmer (2014), "CGE modelling as a framework for absorbing specialist information: linking an energy model and a CGE model to analyse U.S. energy policies**"** chapter 10, pp. 183-200 in G.Das (editor), *Current Issues in International Trade: Methodologies and Development Implications for the World Economy*, Nova Science Publishing

Dixon, P.B and M. T. Rimmer (2016), "Johansen's legacy to CGE modelling: originator and guiding light for 50 years", *Journal of Policy Modeling* 38, pp.421-35.

Dixon, P.B., R.B. Koopman. and M.T. Rimmer (2013), "The MONASH style of CGE modeling: A framework for practical policy analysis", chapter 2, pp. 23-103 in P.B. Dixon and D.W. Jorgenson (editors) *Handbook of Computable General Equilibrium Modeling*, Elsevier, Amsterdam.

Harback, K., S. Martin, S. Tsao, S. Welman, L. Wojcik. P. Dixon, M. Rimmer (2015), "Incorporating Air Transport Congestion into a Computable General Equilibrium Model of the US Economy", presented at the 18th Annual Conference on Global Economic Analysis, Melbourne, Australia, available at https://www.gtap.agecon.purdue.edu/resources/download/7705.pdf.

Johansen, L. (1960), *A Multisectoral Study of Economic Growth*, Contributions to Economic Analysis 21, North-Holland Publishing Company, pp. x+177.

Johansen, L. (1974), *A Multisectoral Study of Economic Growth, second enlarged edition*, Contributions to Economic Analysis 21', North-Holland Publishing Company, pp. x+274.

Metz, D. (2008), "The Myth of Travel Time Saving", *Transport Reviews* 28(3), pp.326-36.

United States International Trade Commission (2004, 2007, 2009, 2011 & 2013), *The Economic Effects of Significant U.S. Import Restraints: Fourth, Fifth, Sixth, Seventh & Eighth Update*, Investigation no. 332-325, Publications 3701, 3906, 4094, 4253 & 4440.

Highlights

- Scientists and engineers build detailed models in energy, environment and transport
- Results from these models can be absorbed in a CGE model
- We link a detailed highway model (HERS) for the U.S. with a CGE model (USAGE)
- The combined model translates HERS highway spending data into economic implications
- We find that increased highway expenditure would have a positive welfare effect

Linking CGE and specialist models:
Deriving the implications of highway policy using USAGE-Hwy

by

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April 2017

Abstract

Scientists/engineers create specialist partial-equilibrium models of energy, environment and transportation. We show how technical information from such models can be transferred into a CGE model. We illustrate the approach by describing the creation and application of USAGE-Hwy which combines USAGE, a CGE model of the U.S., with HERS, a specialist highway model. USAGE-Hwy translates micro information from HERS on the effects of highway expenditure programs into implications for GDP, employment, and the trade-off between current and future living standards. Combination models such as USAGE-Hwy bring scientific/engineering information into the economic domain, facilitating its use in policy discussions.

JEL Classification Codes: C68; L92

Keywords: Linked modelling, CGE modelling, Highway modelling, Highway spending policy

Acknowledgements:

We thank the U.S. Department of Transportation (DOT) and the Australian Research Council (ARC grant no. DP140100476) for financial support. We thank Sean Puckett from DOT for providing results from the HERS model. The analysis and conclusions in the paper are entirely our own. They do not necessarily reflect the views of DOT, the ARC, or any officers in these organizations.