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

by

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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 analyses into the economic domain, facilitating the use of these analyses in policy discussions.

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PRELIMINARY DRAFT

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0. 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 the areas of energy, environment and transportation that can be brought to bear in a CGE framework. This paper shows how information from a specialist highway model, the Highway Economic Requirements System (HERS), can be transferred into a CGE model, USAGE, to deliver policy results that are informed by both modelling techniques. The combined model, USAGE-Hwy, translates detailed micro information from HERS on the effects of highway expenditure programs into implications for variables relevant to decision making in the political arena, including GDP, employment, and the trade-off between current and future standards of living.

There are many versions of USAGE, each including modifications to facilitate particular applications. In creating USAGE-Hwy we started from USAGE-Air that had been created for analyses of the costs and benefits of NextGen aviation technology. The modifications undertaken to USAGE-Air to create USAGE-Hwy are described in section 1. Section 2 describes results taken from HERS to become shocks in USAGE-Hwy. Section 3 reports and explains results for three USAGE-Hwy simulations of the macroeconomic effects of increased expenditure on highways and bridges (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 4.

1. Creation of USAGE-Hwy

We created USAGE-Hwy starting from the 59-industry, 62-commodity USAGE-Air model implemented with 2010 data. For USAGE-Hwy the industry-commodity coverage was

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

expanded to 65 industries and 68 commodities shown in Table 1. In going from USAGE-Air to USAGE-Hwy we made alterations to the USAGE-Air theory and database as detailed below.

1.1. Splitting construction

We split Construction into 3 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 was $89 billion representing 6.1 per cent of total sales of Construction. We assumed that Highways and bridges account for 6.1 per cent of construction expenditure in 2010. Under this assumption, we moved 6.1 per cent of construction inputs into a new industry called Highways and bridges. We gave the H&b inputs the same structure as in the 2005 detailed I-O database. We sold all of the output of H&b to Government and made a corresponding reduction in purchases of Construction by the Government services industry.

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.

1.2. Creating a household car repair (HholdCarRepair) industry and commodity

Car repairs in our 2005 data represents 22.5 per cent of the purchases of Miscellaneous services by households. We created a HholdCarRepair industry worth this much with 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 HholdCarRepair output to PRT (as discussed immediately below).

1.3. Creating a Private road transport (PRT) industry and commodity

We created a Private road transport (PRT) industry and commodity. Intermediate inputs to this industry consist of HholdCarRepair, Motor fuel and Motor vehicles. These inputs were transferred 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 mixing industry[2], Commuter transport (CT) and Vacation transport (VT), in proportion to the purchases in the original database of motor fuel by households and the Vacation industry. The CT industry also buys the original household purchases of Buses, taxis & rail (PassengerTrans), Air transport (AirInternal and Air External) and Water transport (WaterInternal and WaterExternal)). The VT industry buys the original purchases by the Vacation industry of Buses, taxis & rail, Air transport and Water transport. The output of CT is sold to households. The output of VT is sold to the Vacation industry.

1.4. Treating travel time and associated costs

How should we treat travel time? In USAGE-Air, almost all purchases of air services were treated as intermediate inputs (purchase by industries). Household purchases of air services were treated as inputs to the Vacation industry which was modelled as packaging up air

[2] Mixing industries are a convenient mechanism for introducing substitution possibilities. 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.

Table 1. Commodities and industries in USAGE-Hwy

No.	Commodities	No.	Industries
1	Agriculture	1	Agriculture
2	Mining	2	Mining
3	Crude oil	3	Crude oil
4	Natural gas	4	Natural gas
5	Construction	5	Construction
6	Dairy prods & sugar	6	Dairy prods & sugar
7	Meat products	7	Meat products
8	Food manufacturing	8	Food manufacturing
9	Tobacco products	9	Tobacco products
10	Apparel	10	Apparel
11	Textiles	11	Textiles
12	Wood and furniture products	12	Wood and furniture products
13	Paper & publication	13	Paper & publication
14	Chemicals	14	Chemicals
15	Petroleum products	15	Petroleum products
16	Footwear	16	Footwear
17	Metal products	17	Metal products
18	Machinery	18	Machinery
19	Computers	19	Computers
20	Electronic machinery	20	Electronic machinery
21	Motor vehicles	21	Motor vehicles
22	Aircraft	22	Aircraft
23	Aircraft engines	23	Aircraft engines
24	Aircraft equipment	24	Aircraft equipment
25	Transport equipment	25	Transport equipment
26	Navigational equipment	26	Navigational equipment
27	Manufacturing NEC	27	Manufacturing NEC
28	Freight forwarding	28	Freight forwarding
29	Arrangements for Passenger transport	29	Arrangements for Passenger transport
30	Communications	30	Communications
31	Utilities	31	Utilities
32	Trade margins	32	Trade margins
33	Owner-occupier dwellings	33	Owner-occupier dwellings
34	Computer services	34	Computer services
35	Advertising	35	Advertising
36	Legal services	36	Legal services
37	Business and finance services	37	Business and finance services
38	Eating and drinking places	38	Eating and drinking places
39	Medical services	39	Medical services
40	Education	40	Education
41	Social services	41	Social services
42	Government enterprises	42	Government enterprises
43	Non-comparable imports	43	Miscellaneous services
44	Scrap	44	Highways and bridges
45	Used and second hand goods	45	Street repairs
46	Miscellaneous services	46	Private road transport (PRT)

Table 1 continues …

Table 1 continued …

No.	Commodities	No.	Industries
47	Highways and bridges	47	Vacation transport (VT)
48	Street repairs	48	Commuter transport (CT)
49	Private road transport (PRT)	49	HholdCarRepairs
50	Vacation transport (VT)	50	Veterinary services
51	Commuter transport (CT)	51	Government services
52	HholdCarRepairs	52	Vacation
53	Veterinary services	53	Foreign vacation
54	Government services	54	Export Tourism
55	Vacation	55	Other non-residential spending
56	Foreign vacation	56	Auto rental
57	Export Tourism	57	Railroad services, freight
58	Other non-residential spending	58	Buses, taxis & rail (PassengerTrans)
59	Auto rental	59	Trucking services
60	Railroad services, freight	60	Water Transport internal (WaterInternal)
61	Buses, taxis & rail (PassengerTrans)	61	Air Transport internal (AirInternal)
62	Trucking services	62	Pipelines excluding natural gas
63	Water Transport internal (WaterInternal)	63	Natural gas transportation
64	Air Transport internal (AirInternal)	64	Water Transport external (WaterExternal)
65	Pipelines excluding natural gas	65	Air Transport external (AirExternal)
66	Natural gas transportation		
67	Water Transport external (WaterInternal)		
68	Air Transport external (AirExternal)		

services, other transport services, hotel services, etc and selling vacations to households. We estimated air travel time for the base year and introduced equations to explain movements in air travel time in terms of volume of travel and congestion. Then we made industrial users (including the Vacation industry) of air services pay a phantom tax[3] on their purchases which equalled the labor cost of travel time. In this way, we introduced the idea that industries pay for Air services by paying fares plus travel time. To recognize the economy-wide costs of travel time, we deducted travel hours from labor supply available to industries.

Alternatively, we could have treated travel time as a labor input to the air transport industries. While conceptually simple, this approach has three disadvantages relative to what we did: (i) it would not be easy to handle the occupational dimension in the air transport industries; (ii) we would lose the possibility of valuing travel time differently by the industry of the traveller (for example, we would value travel time in the vacation industry as the same as that for a government industry); and (iii) we would treat travel time for freight and passengers as equivalent (if freight increased but passenger stayed constant, then we would not want passenger time to increase).

For USAGE-Hwy we have essentially retained the treatment of air travel time used for USAGE-Air, but we have omitted the congestion specification and simply assumed that air travel time is proportional to passenger miles. We have extended the USAGE-Air approach in USAGE-Hwy to cover not only air travel time but also travel time by private road

[3] A phantom tax is not collected by anyone. However, it boosts the price of the commodity (in this case Air services) on which it is charged. This facilitates the modelling of price signals: it allows USAGE to accurately represent the costs to industries (fares plus travel time) of using air services.

transport, buses, taxis and rail, and water transport. The specific treatment for each of these travel modes is outlined in the rest of this subsection.

Air transport

After the data adjustments described in subsections 1.1 to 1.3, AirInternal[4] sales 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-Air: substitution was allowed against road, rail and water transport services and no modification is 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. Notice that the 40 per cent of sales of AirInternal that go to other industries is not allowed to substitute for 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 journeys supplied by AirInternal is 424.5 million. This is 566*.75 were 566 million is the USAGE-Air number for all airline journeys by U.S. residents and 0.75 is our provisional guess 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.[5] 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 vacations (974) and commuting (16). On (c), we assumed that households value vacation travelling 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 travelling time of $11.89, the value recommended by Volpe. On (d), we decided 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*(974/2000)] million person years from labor supply on account of AirInternal waiting/travelling time associated with VT. In simulations we drive this quantity of waiting/travelling time by the quantity of AirInternal sold to VT. We decided to treat 25 per cent of CT-associated waiting/travelling time as potential labor supply: that is we deduct 0.0020 [= 0.25*(16/2000)] million person years from labor supply. We drive this quantity of waiting/travelling time by the quantity of AirInternal sold to CT. In sensitivity analysis (see subsection 3.5), we change the 0.1 and 0.25 fractions to zero, that is we assume that changes in travel time do not affect labor supply.

With 974 million hours valued at $5 an hour we imposed a phantom sales tax of $4870 million on sales of AirInternal to VT. With 16 million hours valued at $15 an hour we imposed a phantom sales tax of $240 million on sales of AirInternal to CT. We drive the collection of these sales taxes by the nominal wage rate and by the quantity of sales of

[4] This industry provides passenger and freight air services within the U.S. USAGE-Hwy includes a second air transport industry, AirExternal, that provides air services internationally.
[5] Passenger sales are all sales excluding margin sales.

AirInternal to VT and CT. All of these decisions are summarized in the AirInternal rows of Table 2.

By contrast with AirInternal, we have not allowed for travel time used in AirExternal. USAGE-Hwy is focused on the effects of highway improvements which save time in road transport, thereby affecting the competitiveness of road transport relative to other modes of transport within the U.S. To adequately reflect transport competitiveness effects in the U.S. it is necessary to consider time use in all modes of internal transport, but it is not necessary to model time use in external air transport which barely competes with internal transport.

Private road transport (PRT)

The spread sheet received from Volpe in July 2013 indicates that VMT for passenger cars in 2010 was 2,253,110 million miles. Volpe's spread sheet implies that travel time cost in 2010 for passenger cars was $986,186m [=2,253,110*437.7/1000, where $437.7 is Volpe's estimate of time cost per 1,000 VMT]. Volpe 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 (we assume 25 per cent for CT and 10 per cent for VT).

We assume that Volpe's 2,253,110 million miles is spread between VT and CT in the proportions 17,381 to 79,179. This split was decided on the basis of purchases in the original database of motor fuel by households and the Vacation industry. Thus we assume that VT travel is 405,564m miles and CT travel is 1,847,546m miles. Continuing to assume hourly travel costs of $5 per hour for VT and $15 per hour for CT, we can hit the Volpe cost number by assuming that the average speed of vehicles is 30.16 miles per hour. This gives time lost in VT travel of 13,448m hours (=405564/30.16) and time lost in CT travel of 61,263m hours (=1847564/30.16) with corresponding costs of $67,241m (=13448*5) and $918,945m (=61263*15). These costs are treated as phantom taxes on sales of PRT to VT and CT. We drive the collections of these sales taxes by the nominal wage rate and by the quantity of sales of PRT to VT and CT. Assuming 2000 hours in a person-work year and continuing to use our labor supply fractions of 0.1 and 0.25 we calculate the reductions in labor supply as 0.6724 (= 0.1*13448/2000) and 7.6579 (=0.25*61263/2000) million person years.

Table 2. 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	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	974	0.1	0.0487	$4,870
PRT	5	13,448	0.1	0.6724	$67,241
PassengTrans	5	5,910	0.1	0.2955	$29,550
WaterInternal	0	0	0.0	0.0	0
Sales to CT					
AirInternal	15	16	0.25	0.002	$240
PRT	15	61,263	0.25	7.6579	$918,945
PassengTrans	15	8,704	0.25	1.0881	$130,568
WaterInternal	15	384	0.25	0.0479	$5,753

All of these decisions are summarized in the PRTs rows of Table 2.

Buses, taxis and rail (PassengerTrans)

After the adjustments so far, PassengTrans sales (excluding tiny sales to inventories and exports) in the 2010 database are as follows: 27.8 per cent to VT, 40.9 per cent to CT and the rest (31.3 per cent) to other industries. We needed to: (a) put in substitution elasticities between intermediate inputs in the VT and CT industries; (b) decide how much time is taken by households in using the services of PassengTrans that are intermediate inputs to VT and CT; (c) decide what values to place on this time; and (d) decide how much of this time to treat as a deduction from labor supply. Notice that the 31.3 per cent of sales of PassengrTrans that go to other industries is not allowed to substitute for other modes of transport.

On (a), we decided previously to use a substitution elasticity of 2. On (b) we noted that the values of consumer purchases and Vacation purchases of PassengTrans in the original input-output data were $34,818m and $23,640m. We guess that the average fare is $4, implying that the numbers of journeys are 8,704.5 million and 5,910 million. We assume that each journey takes 1 hour, giving 8704.5 million hours associated with CT travel and 5,910 million hours associated with VT travel. On (c), we assumed that households value PassengTrans time associated with Vacation at $5 an hour and PassengTrans time associated with CT at $15 an hour. On (d), we decided to treat 25 per cent of PassengTrans waiting/travelling time associated with sales to CT as potential labor supply: that is we deducted 1.0881 [= 0.25*(8704.5 /2000)] million person years from labor supply. We decided to treat 10 per cent of PassengTrans waiting/travelling time associated with sales to VT as potential labor supply: that is we deducted 0.2955 [= 0.10*(5910/2000)] million person years from labor supply. We drive these quantities of waiting/travelling time by the quantities of PassengTrans sold to CT and VT.

With 5,910 million hours valued at $5 an hour we imposed a phantom sales tax of $29,550 million on sales of PassengTrans to VT. With 8,704.5 million hours valued at $15 an hour we imposed a phantom sales tax of $130,567.5 million on sales of PassengTrans to CT. We drive the collections of these sales taxes by the nominal wage rate and by the quantity of sales of PassengTrans to VT and CT.

All of these decisions are summarized in the PassengTrans rows of Table 2.

Water transport

After the adjustments so far, WaterInternal sales (excluding tiny sales to inventories) 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. The sales of WaterInternal for margin purposes were handled satisfactorily in USAGE-Air: substitution was allowed against road, rail and air. For USAGE-Hwy needed to: (a) put in substitution elasticities between intermediate inputs in the VT and CT industries; (b) decide how much time is taken by households in using the services of WaterInternal that are intermediate inputs to VT and CT; (c) decide what values to place on this time; and (d) decide how much of this time to treat as a deduction from labor supply. Notice that the 25.8 per cent of sales of WaterInternal that go to other industries is not allowed to substitute for other modes of transport.

On (a), we decided earlier to use a substitution elasticity of 2. On (b) in the case of WaterInternal, we noted that the value of consumer purchases and the sales to the Vacation industry in the original input-output data were $1,534m and $8,734m. We guess that the average commuter fare is $4, implying that the total number of commuter journeys is 383.5 million [= 1534/4]. We assume that each commuter journey takes 1 hour, giving 383.5 million hours associated with CT travel. For VT, we assumed that WaterInternal is an integral part of a vacation. Thus we do not need to calculate associated time costs. On (c), we assumed that households value WaterInternal time associated with commuting at $15 an hour. On (d), we decided to treat 25 per cent of WaterInternal waiting/travelling time associated with sales to CT as potential labor supply: that is we deducted 0.0479 [= 0.25*(383.5 /2000)] million person years from labor supply. We drove this quantity of waiting/travelling time by the quantity of WaterInternal sold to CT.

With 383.5 million hours valued at $15 an hour we imposed a phantom sales tax of $5,752.5 million on sales of WaterInternal to CT. We drove the collection of these sales taxes by the nominal wage rate and by the quantity of sales of WaterInternal to CT. All of these decisions are summarized in the WaterInternal rows of Table 2.

As in the case of AirExternal, for USAGE-Hwy we did not allow for time use in WaterExternal.

1.5. 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. In terms of algebra, we compute

$$W_t = \sum_c S_t(c) * \left[\frac{X_t^P(c) - X_t^B(c)}{X_t^B(c)} \right] * 100 \qquad (1.1)$$

where

W_t is the welfare effect in year t;

$X_t^P(c)$ 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 (1.1) is closely related to two other welfare concepts: equivalent variation (EV) and compensating variation (CV). With Laspeyres shares, (1.1) is an overestimate of EV and with Paasche shares (1,1) is an underestimate of CV.[6] However, CV, EV and all variants of (1.1) 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 (1.1). 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 (1.1) to show a reduction in welfare. Similarly, if a highway project causes medical expenditures to fall, then (1.1) records a welfare increase via additional expenditures on other commodities.

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[6] See for example page 210 of 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.

Highway projects change the number of road fatalities. The second modification that we made to (1.1) allows for road fatalities valued as a welfare reduction of $6.8m (2010 prices) per fatality. This is the standard valuation used by DOT and recommended to us by Volpe.

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, (1.1). 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:

$$0.01*W_t = \sum_{c\neq Med} S_t^{\#}(c)*\left[\frac{X_t^P(c)-X_t^B(c)}{X_t^B(c)}\right] - \frac{6.8*CPI_t^{\#B}}{CPI_{2010}^{\#B}}*\frac{d\_fatal_t}{AGGCON_t^{\#B}} + \frac{d\_v\_timesave_t}{AGGCON_t^{\#B}} - \frac{d\_v\_employ\_disutility_t}{AGGCON_t^{\#B}} \qquad (1.2)$$

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.

2. The shocks

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 analysing the effects of increased highway infrastructure expenditure, we applied seven sets of shocks based on the HERS spread sheet sent to us by Volpe in July 2013. The shocks refer to differences between a HERS baseline run and a HERS increased-investment run.

2.1 Public expenditure on highways and bridges (H&b)

Chart 2.1 shows the paths of these expenditures in the two HERS runs out to 2040. Chart 2.2 expresses the differences in the expenditures as percentages of baseline GDP. As can be seen from the two charts, 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.

2.2. Road maintenance savings

The HERS spread sheet implies that additional infrastructure expenditure generates savings in road maintenance. These savings are shown in Chart 2.3. Relative to the additional highway expenditures (Charts 2.1 and 2.2), the maintenance savings in Chart 2.3 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 two lines in Chart 2.1) is $28,381m. The maintenance savings in 2020 are $81m. Thus our shock 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.

2.3. Vehicle operating costs

As shown in Chart 2.4, the HERS spread sheet implies 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 simulations we introduced the savings shown in Chart 2.4 as uniform savings across all intermediate inputs in the Private road transport industry and the Trucking services industry.

2.4. Fuel saving

As shown in Chart 2.5, the HERS spread sheet implies that additional highway investment increases fuel use per mile travelled, presumably because of higher speeds. Extra fuel use per mile travelled peaks at 0.75 per cent for passenger vehicles in 2025. In simulations we introduced the information shown in Chart 2.5 for passenger vehicles as shocks to fuel use per unit of output in the Private road transport industry. We introduced the information for Trucking services as shocks to fuel use per unit of output in all other industries. Fuel is part of vehicle operating costs. However we did not allow the shocks to fuel costs to affect overall vehicle operating costs in the Private road transport 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 introduced in subsection 2.3.

2.5. Safety costs

We understand from Volpe that safety costs shown in the HERS spread sheet include an allowance for policy-induced fatalities at $6.8m (2010 prices). As explained in section 1.5, we treated fatalities as a separate item in our welfare function. Consequently we excluded the value of fatalities from safety costs. We then charted safety costs excluding the value of fatalities.

Chart 2.1. Paths of Highway and bridge expenditure ($m 2010 prices)

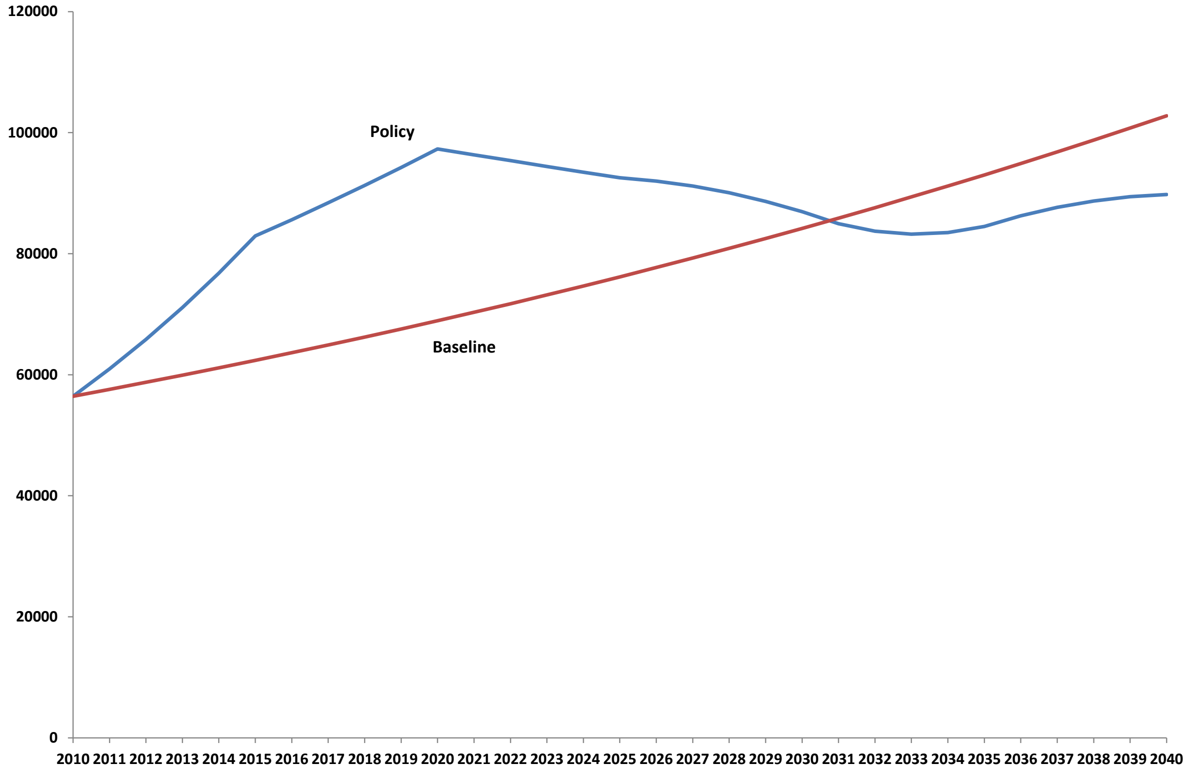


Chart 2.2. Deviation in Highway and bridge expenditure as per cent of GDP

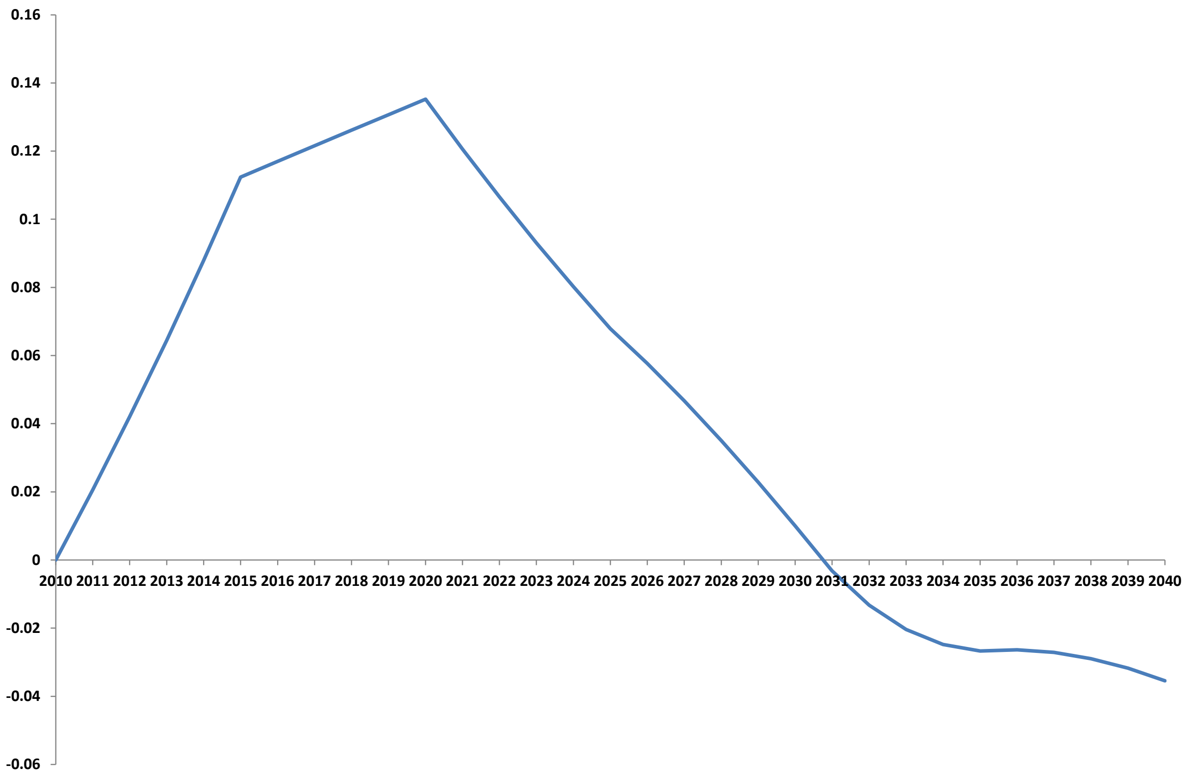


Chart 2.3. Maintenance cost savings ($m 2010 prices, increased investment - baseline)

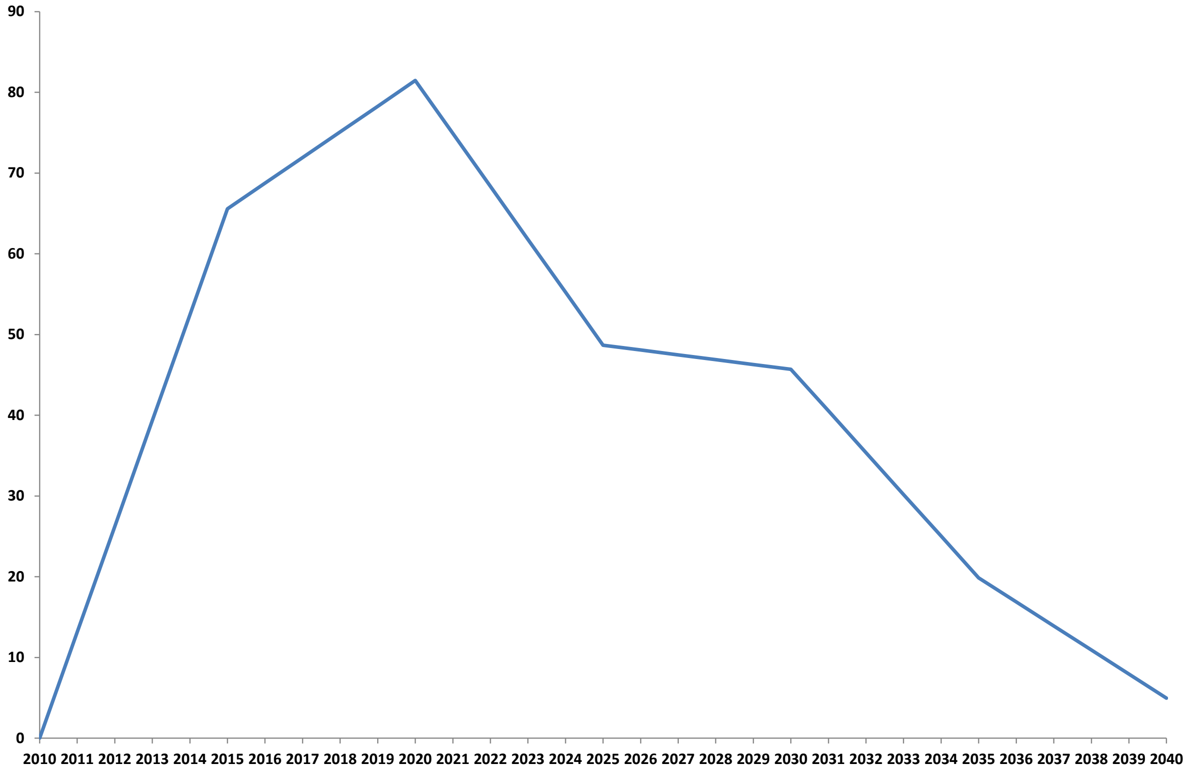


Chart 2.4. Percentage changes in vehicle operating costs per mile travelled

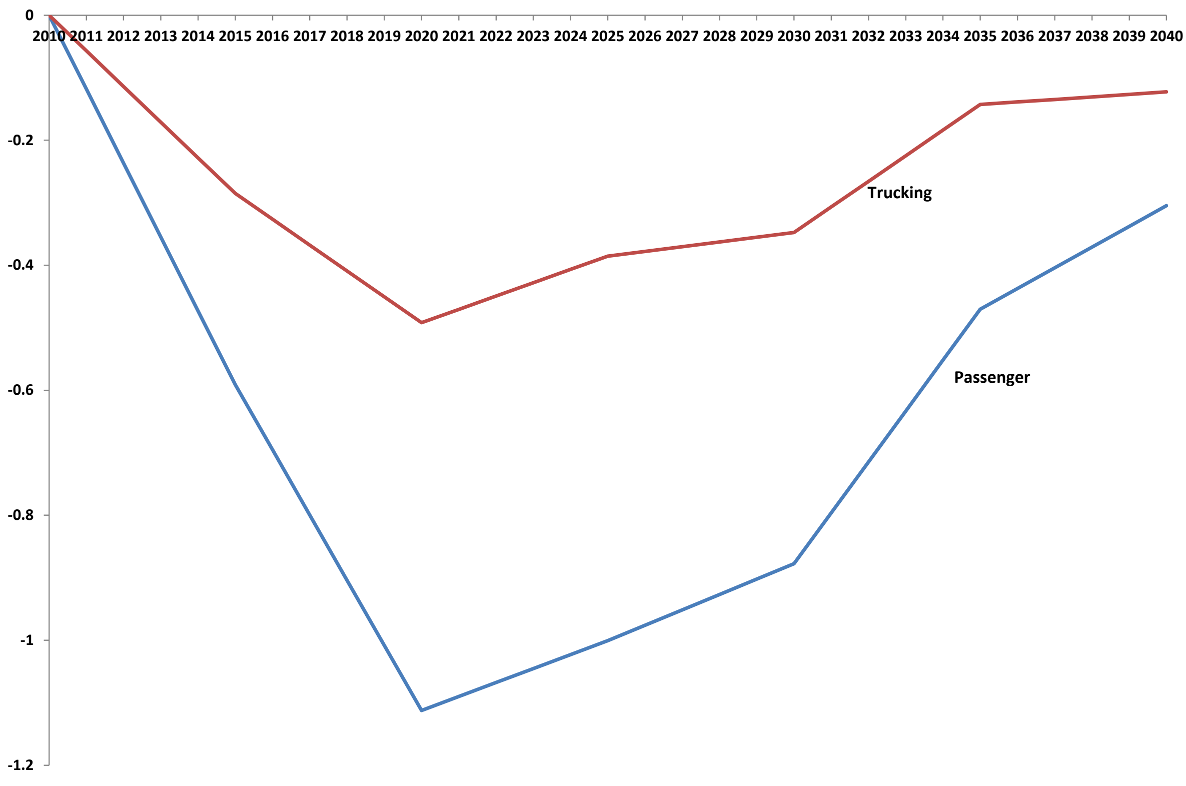
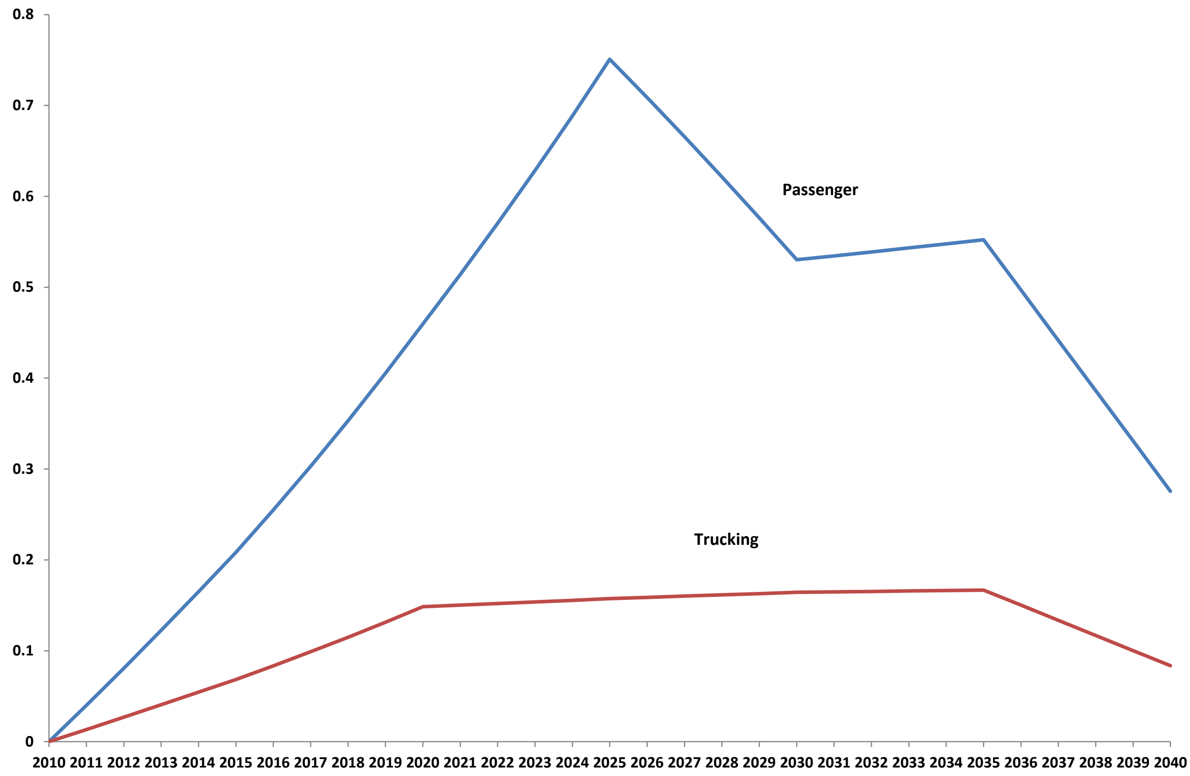


Chart 2.5. Percentage changes in fuel use per mile travelled



As shown in Charts 2.6 and 2.7, the HERS spread sheet implies that additional highway investment increases safety costs net of fatalities, presumably because of higher speeds and increased highway use. In simulations we introduced this information as additional purchases of medical services by the household sector. As mentioned in section 1.5, in measuring welfare we excluded medical expenditures. Thus, the additional medical expenditures imposed on households are welfare-reducing: they reduce the ability of households to consume welfare-enhancing products.

Charts 2.6 and 2.7 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 safety costs are quite small and do not warrant the use of sophisticated smoothing procedures.

2.6. Fatalities

As shown in Chart 2.8, the HERS spread sheet implies that additional highway investment affects the number of fatalities on U.S. roads. In 2040, extra fatalities per year reach nearly 300. The extra fatalities are due to increased VMT associated with additional highway expenditure.[7]

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[7] As discussed in our second progress report (September 19, 2013) the Volpe spread sheet shows a fluctuating series for the effect of additional highway expenditure on fatalities per VMT. In drawing Chart 2.8 in the current report, we left out this fluctuating effect: we assumed that fatalities per VMT are not affected by increased infrastructure expenditure. We did this after discussion at the workshop of November 12-13.

Chart 2.6. Extra safety costs associated with increased highway investment expenditure ($m 2010 prices)

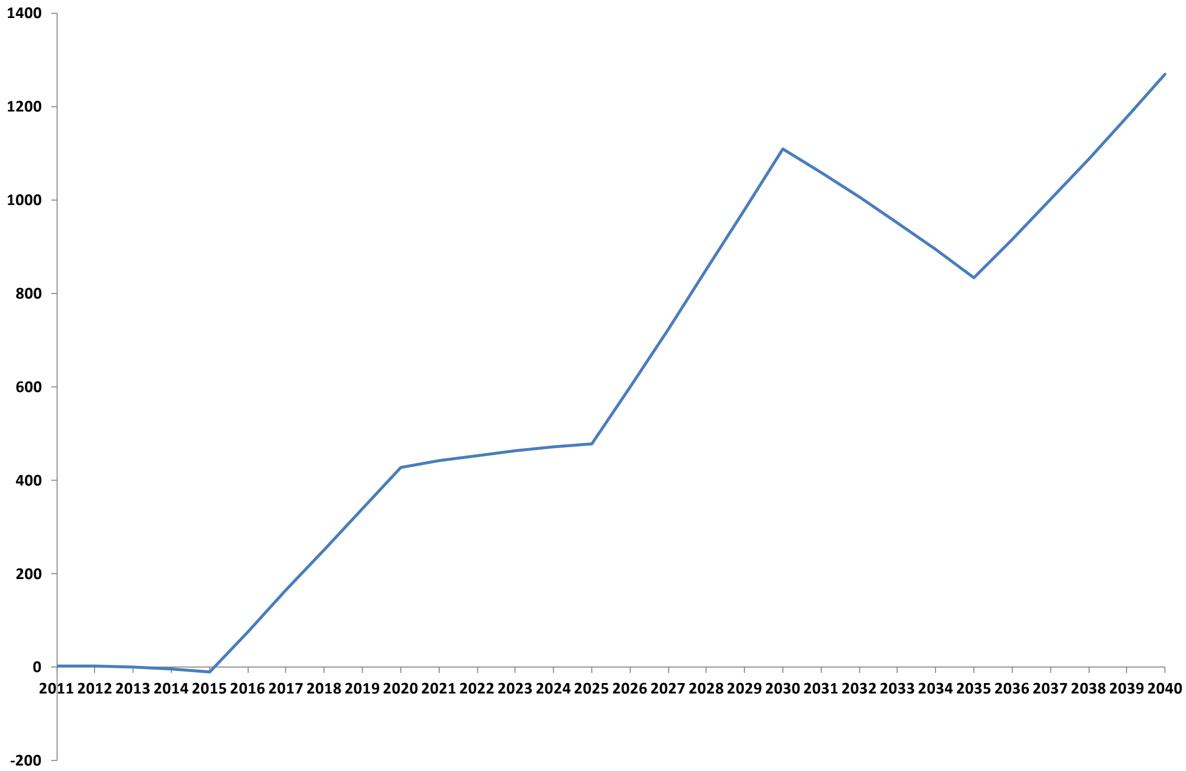


Chart 2.7. Deviation in safety costs as per cent of GDP

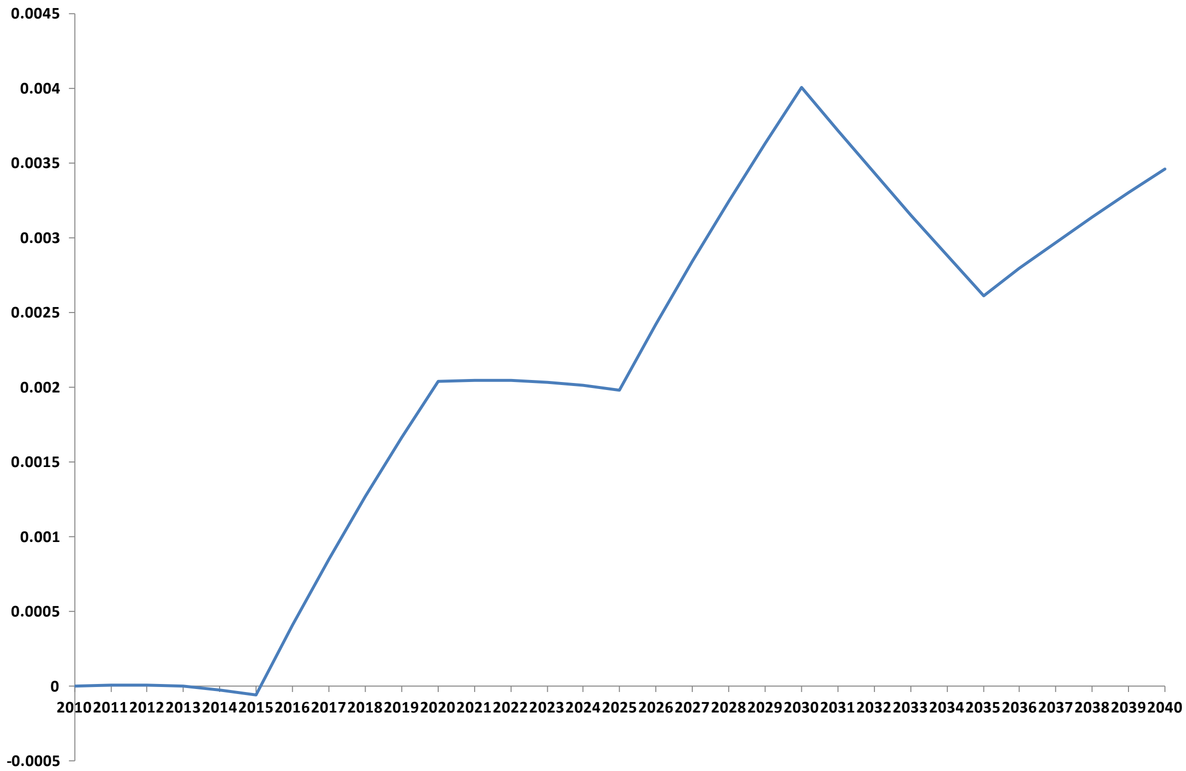
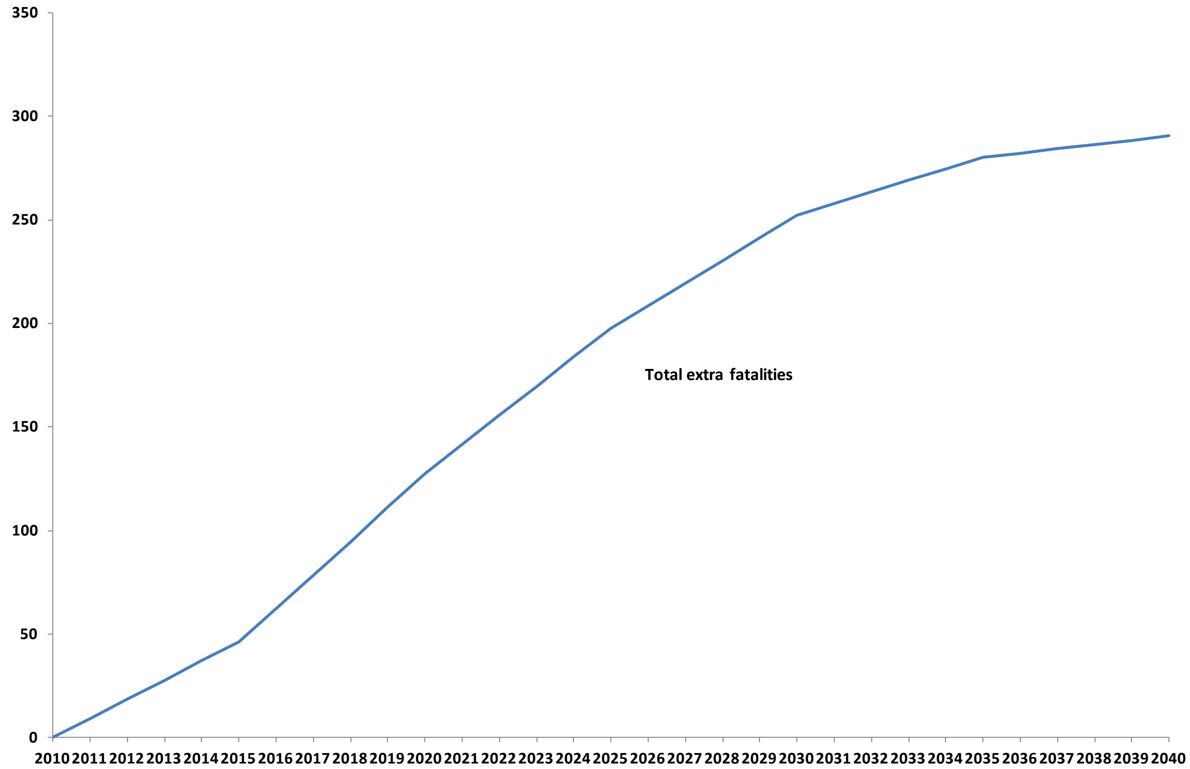


Chart 2.8. Extra fatalities associated with increased highway investment expenditure



2.7. Saving of travel time

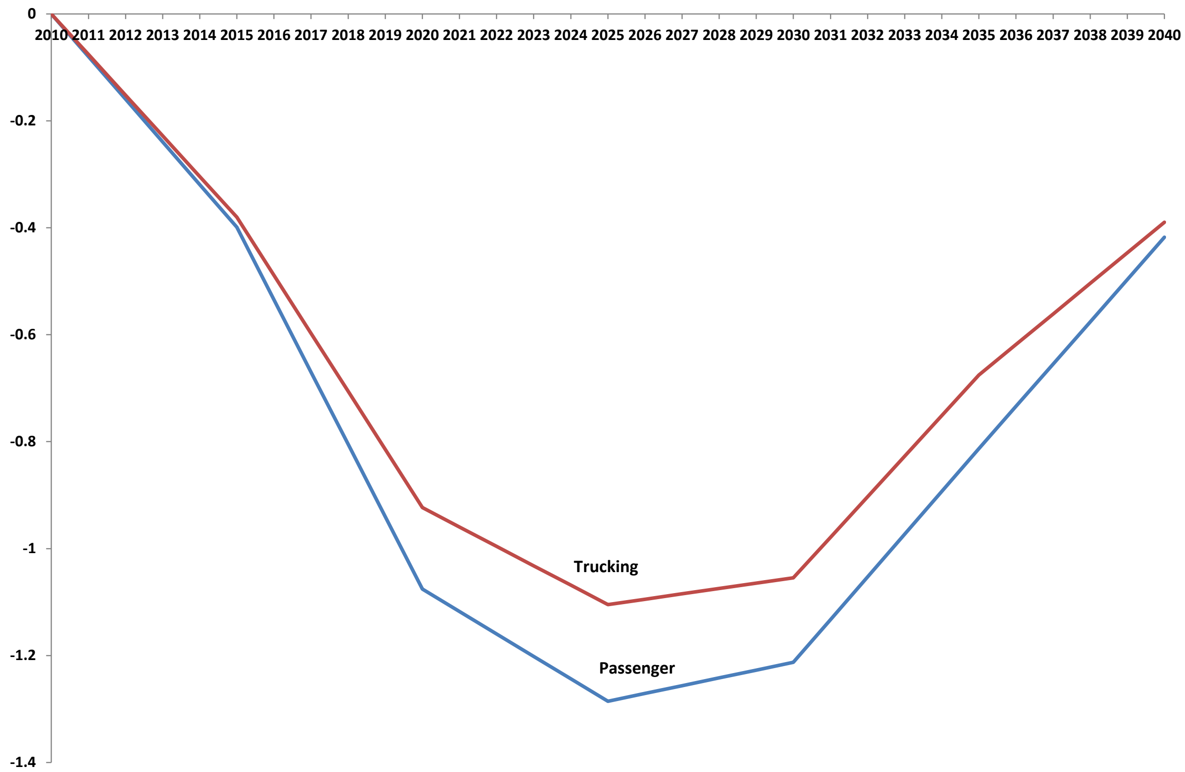
As shown in Chart 2.9, the HERS spread sheet implies that additional highway investment will reduce time per VMT for both passenger vehicles and trucks. In simulations, we introduce the information in Chart 2.9 for passenger vehicles as percentage shocks to household time required per unit of sales of Private road transport to Commuter transport and to Vacation transport, see the discussion of Private road transport in subsection 1.4. For Trucking services, the information in Chart 2.9 was applied as percentage shocks to labor input per unit of output.

3. Effects of highway and bridge (H&b) expenditure under three financing options

Subsections 3.1 to 3.4 report three simulations each with the same baseline and policy shocks, the shocks described in section 2. These simulations differ only in their financing assumptions. In simulation 1, 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 simulation 2, 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 simulation 3, 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 simulation 2, the rate of the tax is varied so that the deficit/GDP ratio in the policy run follows its baseline path.

Subsection 3.5 reports three sensitivity simulations, simulations 4 to 6. In the sensitivity simulations we change our assumptions regarding the link between travel time saving and

Chart 2.9. Percentage reductions in time per VMT associated with increased highway investment expenditure



labor supply. In simulations 1 to 3 we assumed that 10 per cent of vacation travel time saved through highway improvement and 25 per cent of saved commuter travel time is translated into increased labor supply (see subsection 1.4). These percentages were considered somewhat too high by some participants in the workshop of November 12-13. Simulations 4 to 6 repeat simulations 1 to 3 but with none of the saved travel time feeding into labor supply.

3.1. Overview of the main results: employment and welfare in simulations 1 to 3

Chart 3.1 shows the effects of H&b expenditure on aggregate employment in simulations 1 to 3. 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 favorable in the early years with lump-sum taxation that with deficit financing, but more favorable 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 3.2 shows the effects of H&b expenditure on aggregate welfare measured according to equation 1.2 in subsection 1.5. This measure allows for private consumption net of medical expenses, leisure and road fatalities. 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

Chart 3.1. Aggregate Employment
(percentage deviations from baseline)

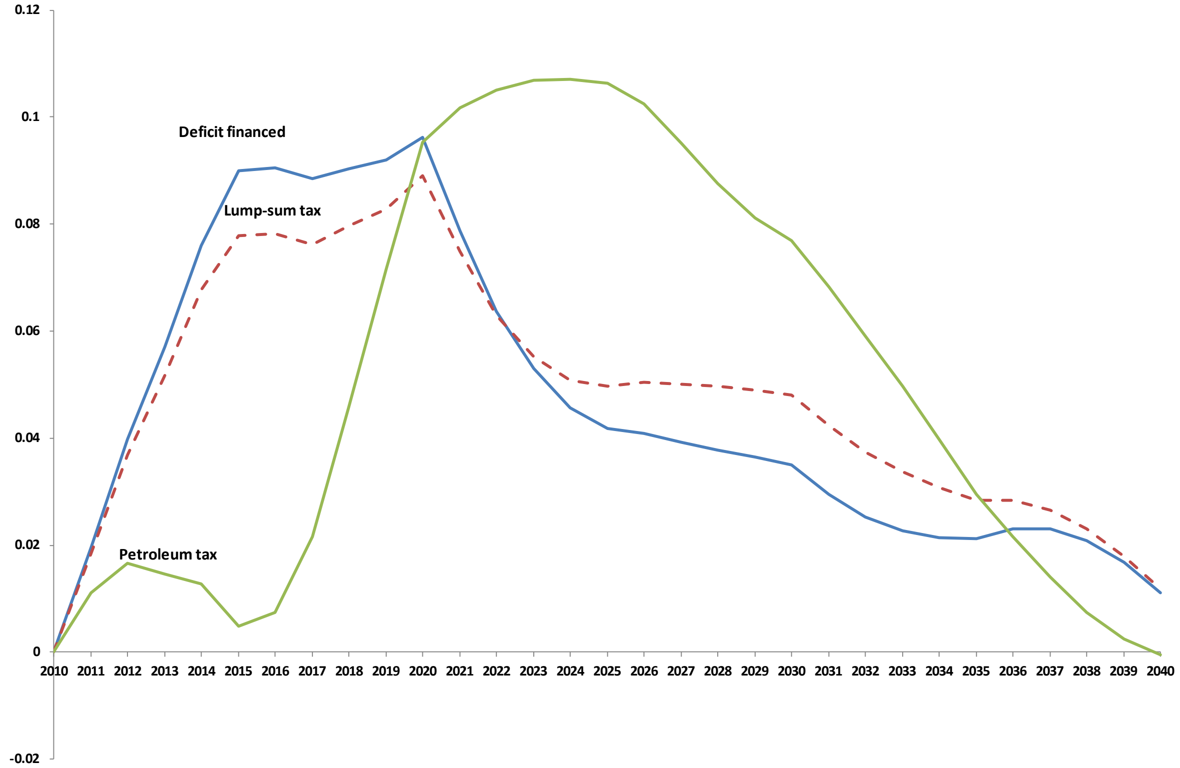
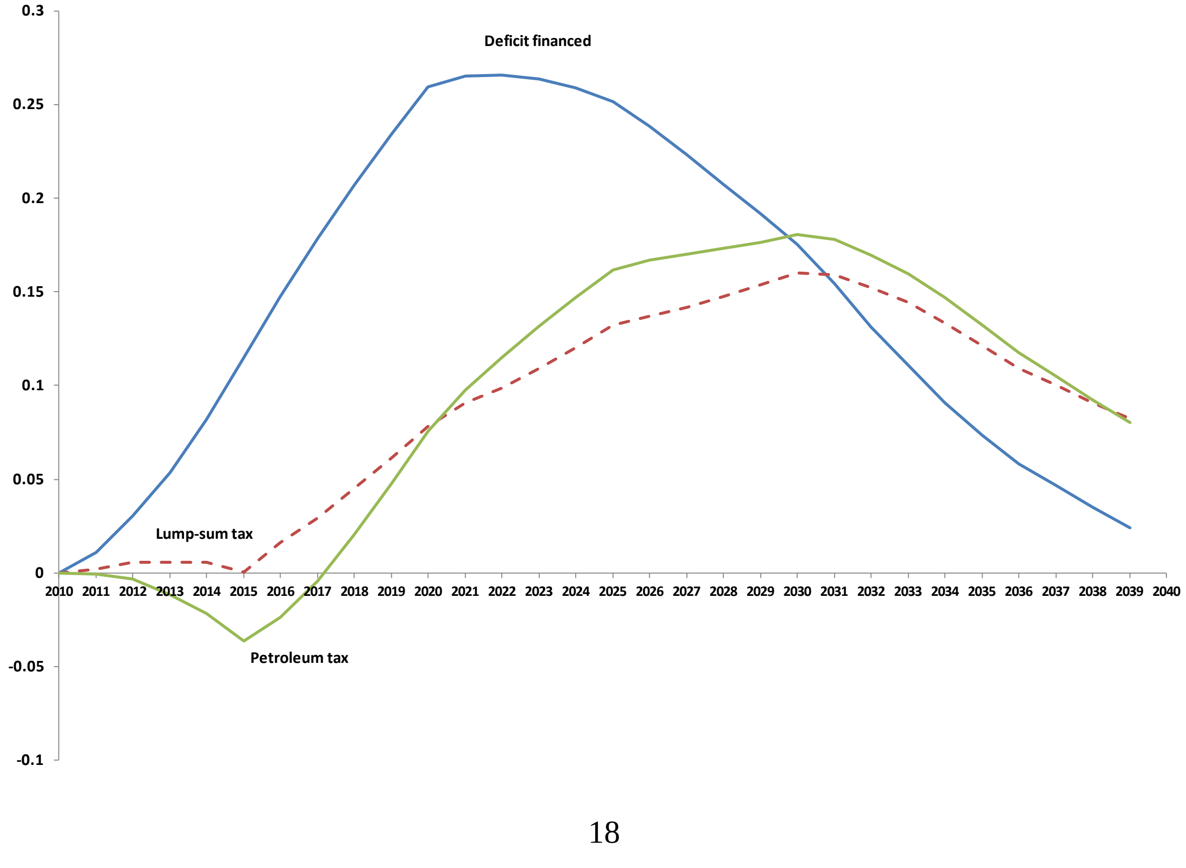


Chart 3.2. Aggregate Welfare
(percentage deviations from baseline)



approximately zero until 2015. Beyond 2015 the welfare deviations increase steadily until 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 3.2 for deficit financing average 0.151. The average deviations in the lump-sum and petroleum tax simulations are 0.091 and 0.095. With a 4 per cent discount rate, the three averages are 0.089, 0.045 and 0.044.

Subsections 3.2 to 3.4 explain the employment and welfare results in detail and cover several other macro variables.

3.2. Deficit financing

Chart 3.3 gives labor-market results for the effects of increased H&b expenditure under deficit financing. For understanding these results, a useful back-of-the-envelope (BOTE) equation is

$$W = P_{gdp} * A * F_l(K/L) \qquad (3.1)$$

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

$A * F_l(K/L)$ 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 (3.1) is a stylized version of the assumption built into CGE models such as USAGE that employers will hire labor up to the point at which the wage rate equals the value of the marginal product of labor.

Dividing both sides of (3.1) by the price deflator for consumption (P_c) gives

$$\frac{W}{P_c} = \frac{P_{gdp}}{P_c} * A * F_l(K/L) \qquad (3.2)$$

The LHS of (3.2) is the real wage rate from the point of view of consumers.

In USAGE policy runs we assume that this 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 RHS of (3.2), the H&b investment program causes an increase in A through saving of time and intermediate inputs in the Trucking services and Private road transport industries. The program also generates an increase in P_{gdp}/P_c for two reasons. First, 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. 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).[8] These effects can be seen in Chart 3.4. An improvement in

[8] 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. Cost increases in the U.S. cause leftward movements in U.S. export-supply curves with consequent increases in foreign currency prices of U.S. exports. On the import side, increases in U.S. demands

Chart 3.3. Labor market variables: H&b expenditures financed by deficit spending (percentage deviations from baseline)

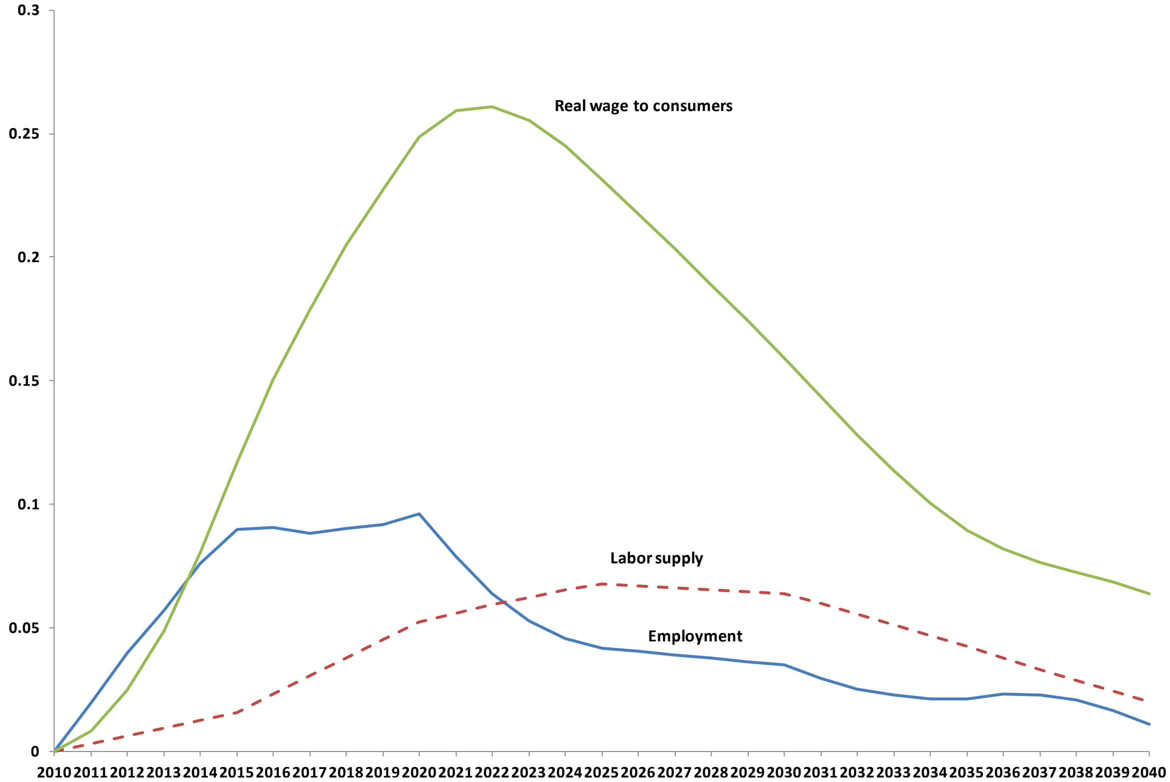
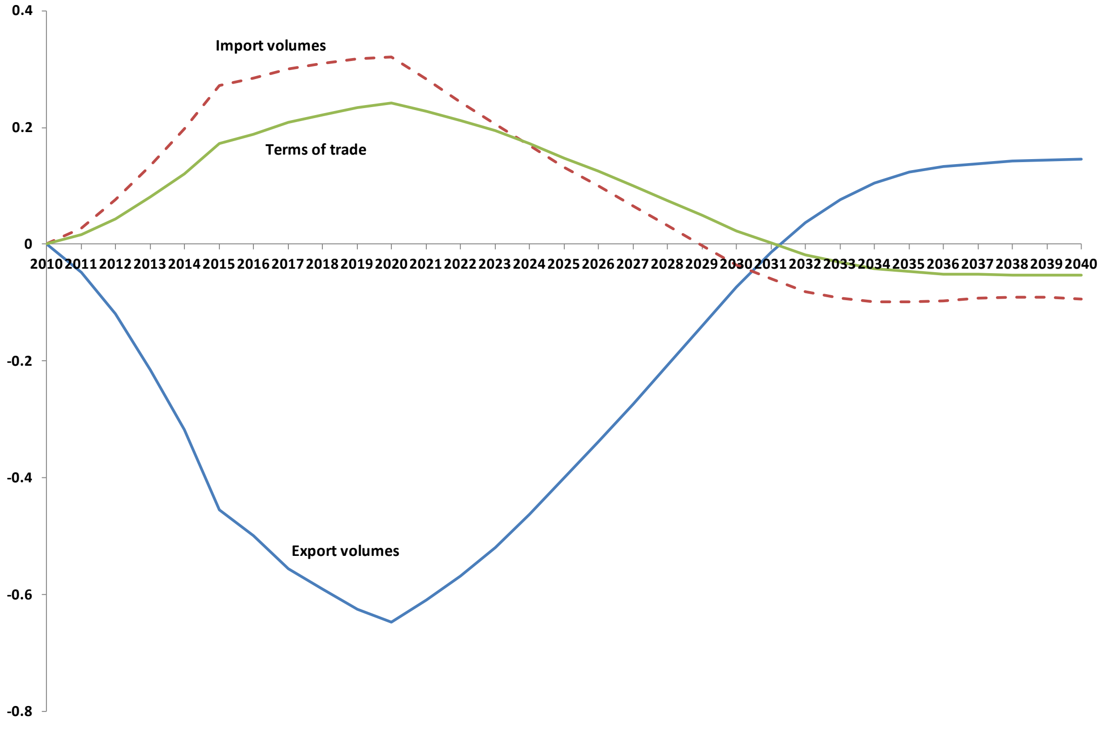


Chart 3.4. Trade variables: H&b expenditures financed by deficit spending (percentage deviations from baseline)



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do not affect foreign-currency import prices. Thus increases in the U.S. price level associated with deficit-financed expenditure generate a terms-of-trade improvement via an increase in foreign-currency export prices with no offsetting effect on import prices.

the terms of trade raises the price of GDP relative to the price of goods and services absorbed in the U.S. (the price of gross national expenditure, P_{gne}). 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. Thus movements in P_{gdp}/P_{gne} are closely correlated with the terms of trade. With private consumption being the dominant component of absorption, in most simulations, including the one being discussed here, improvements in the terms of trade generate increases in P_{gdp}/P_c. 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_{gdp}/P_c increases relative to P_{gdp}/P_{gne} which as we have already explained increases via the terms of trade.

With sticky adjustment in W/P_c and increases in A and P_{gdp}/P_c, preservation of equation (3.2) requires a reduction in $F_l(K/L)$ which in turn requires a reduction in K/L. In the short run, K can be considered fixed. Thus, L must increase.

Going beyond equation (3.2), there is another factor which contributes to the H&b-induced increase in employment in the results for the early years in Chart 3.3. 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 2.2), the employment deviation in Chart 3.3 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 2.9. However, the initial percentage increases in labor demand 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 2.4 and 2.9) to allow positive deviations in real wages, labor supply and employment.

Chart 3.5 shows deviations in GDP and contributing components. It can be understood via the equation

$$y = a + S_L * l + S_K * k \qquad (3.3)$$

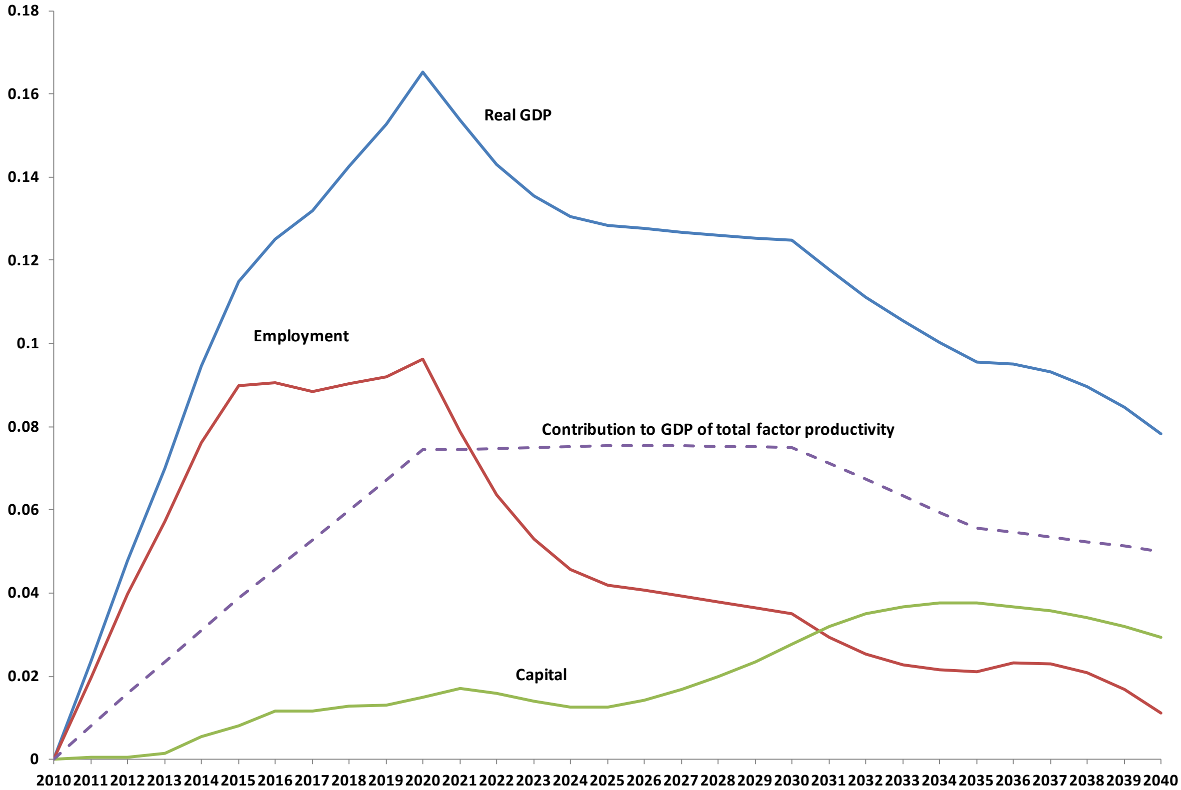
where

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 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 economy of 2010. Most of this deviation is contributed by total factor productivity and employment. Capital also makes a positive contribution.

Chart 3.5. GDP and factor inputs: H&b expenditures financed by deficit spending

(percentage deviations from baseline)



A useful equation for understanding the positive deviations in capital is

$$\frac{Q}{P_i} = \frac{P_{gdp}}{P_i} * A * F_k(K/L) \tag{3.4}$$

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 (3.2). 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 RHS of (3.4). P_{gdp}/P_i is also affected by the H&b expenditure program. However, the A and K/L affects 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 3.5 throughout the simulation period.

To conclude this subsection we return to the welfare deviations shown for deficit financing in Chart 3.2. 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 3.4, 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 2.9) and saving of vehicle operating costs (Chart 2.4) explains why the welfare deviation under deficit financing declines towards zero in the second half of the simulation period.

3.3. Lump-sum-tax financing

Results for lump-sum-tax financing are in Charts 3.6 to 3.8. 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 in Chart 3.6 (also see Chart 3.2), the welfare deviations are lower with lump-sum taxation than with deficit financing. However, the macroeconomic effects of H&b expenditures continue to be favorable, see Chart 3.8. Employment is initially stimulated by the labor intensity of H&b expenditures. In terms of equation (3.5), 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. The increase in P_{gdp}/P_c. can be explained in two steps. First, the shift in gross national expenditure (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 the price of GNE increases relative to the price of consumption. 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} relative to P_{gne}. Thus, P_{gdp} rises relative to P_c.

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 3.8 and 3.5. 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 3.7 and 3.4. A remaining question is why do exports decline at all under tax financing.

An equation that helps us understand this result is:

$$Y = C + I + G + X - M \qquad (3.5)$$

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 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 3.2 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.

Chart 3.6. Labor market variables: H&b expenditures financed by a lump-sum tax (percentage deviations from baseline)

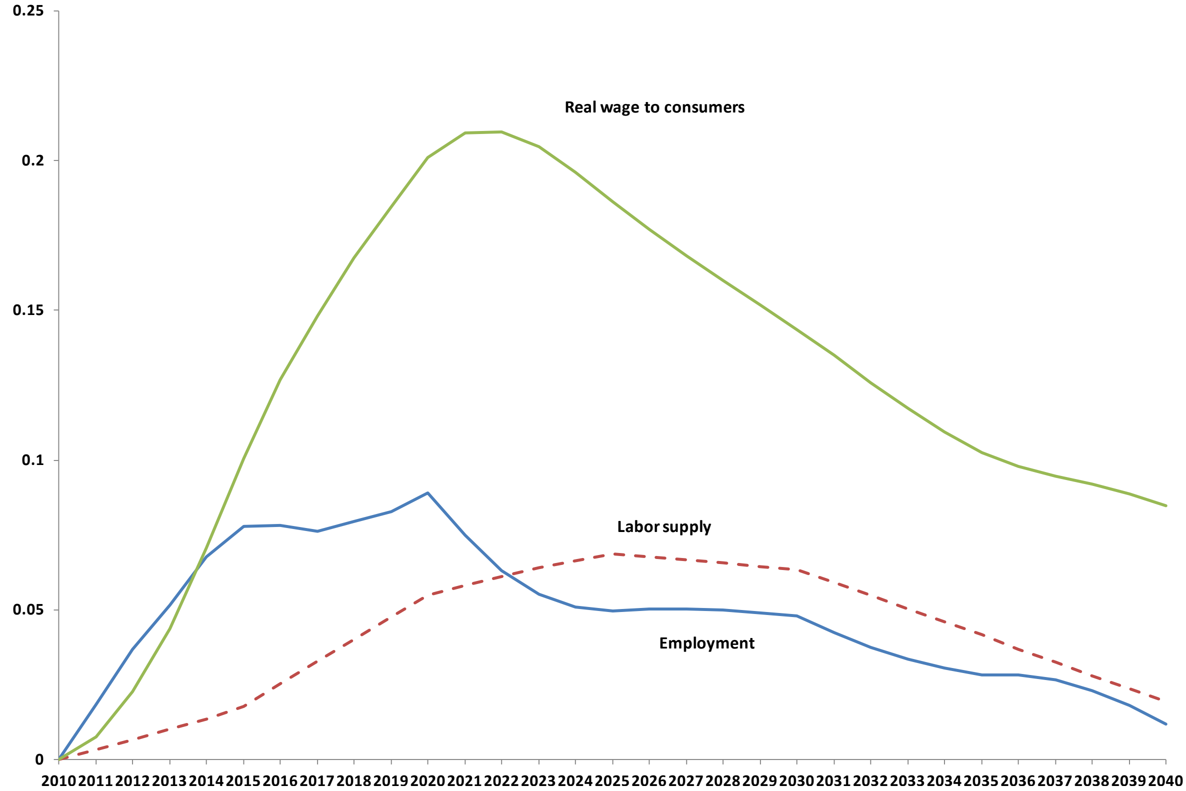


Chart 3.7. Trade variables: H&b expenditures financed by a lump-sum tax (percentage deviations from baseline)

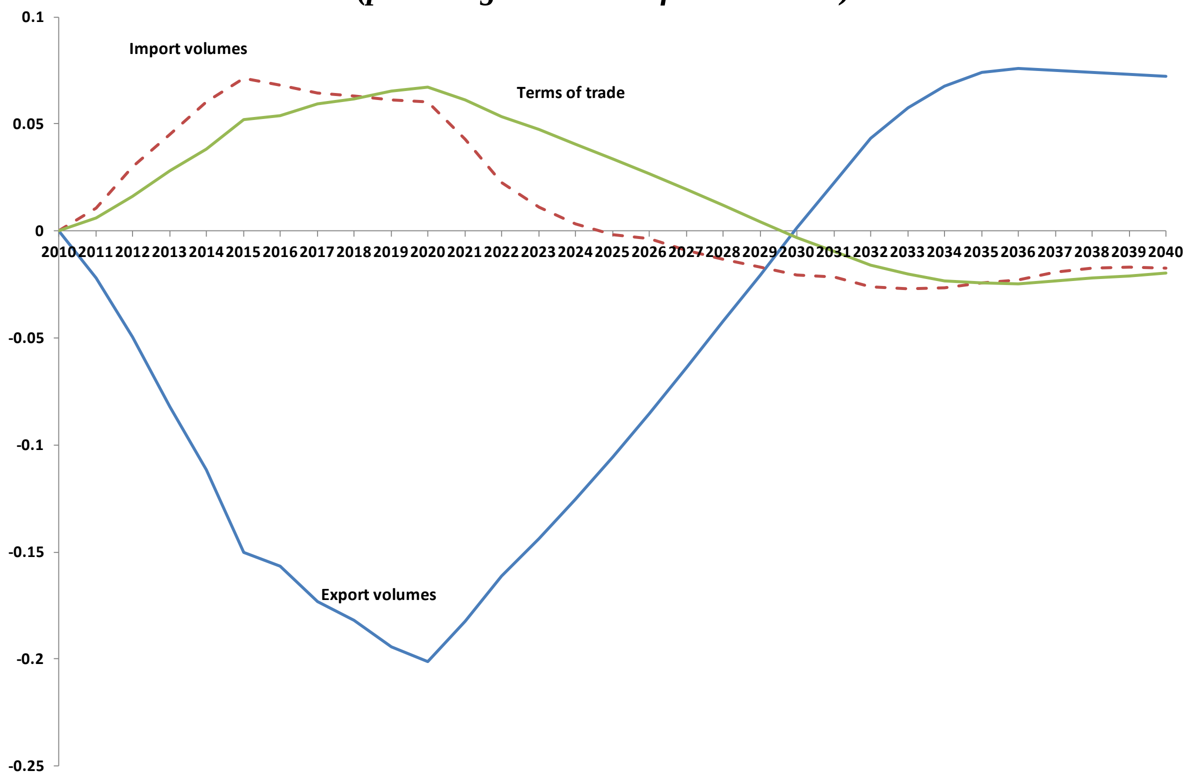
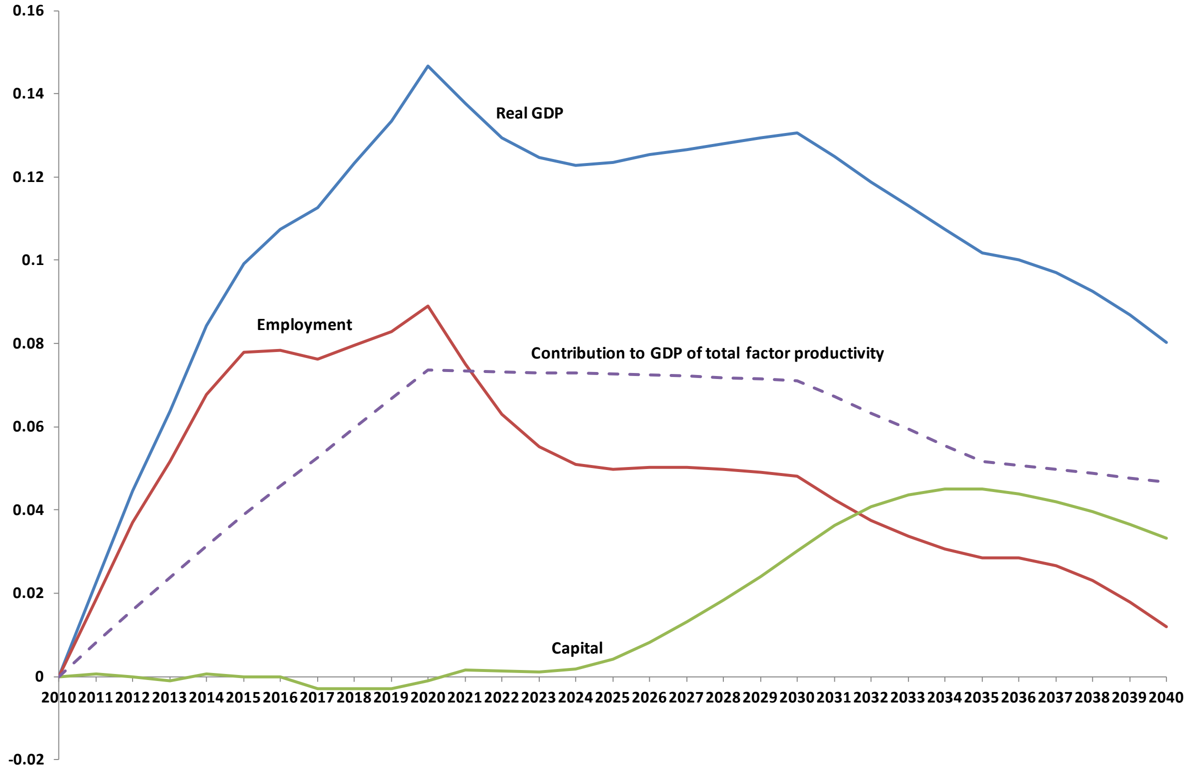


Chart 3.8. GDP and factor inputs: H&b expenditures financed by a lump-sum tax (percentage deviations from baseline)



3.4. Petroleum-tax financing

Results for petroleum-tax financing are in Charts 3.9 to 3.11. In the years up to 2016, the employment effects of H&b spending under petroleum-tax financing are barely positive, see Chart 3.1 or 3.9. To understand this result we need a refined version of equation (3.2):

$$\frac{W}{P_c} = \frac{P_{gdp}}{P_c} * (1 - T) * A * F_l(K/L) \qquad (3.6)$$

In (3.6) 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 (3.6), the introduction of a petroleum tax to finance H&b expenditures is equivalent to an increase in T. The increase in T, that is the decrease in (1 - T), causes $F_l(K/L)$ 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 $F_l(K/L)$ 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

Chart 3.9. Labor market variables: H&b expenditures financed by a petroleum tax (percentage deviations from baseline)

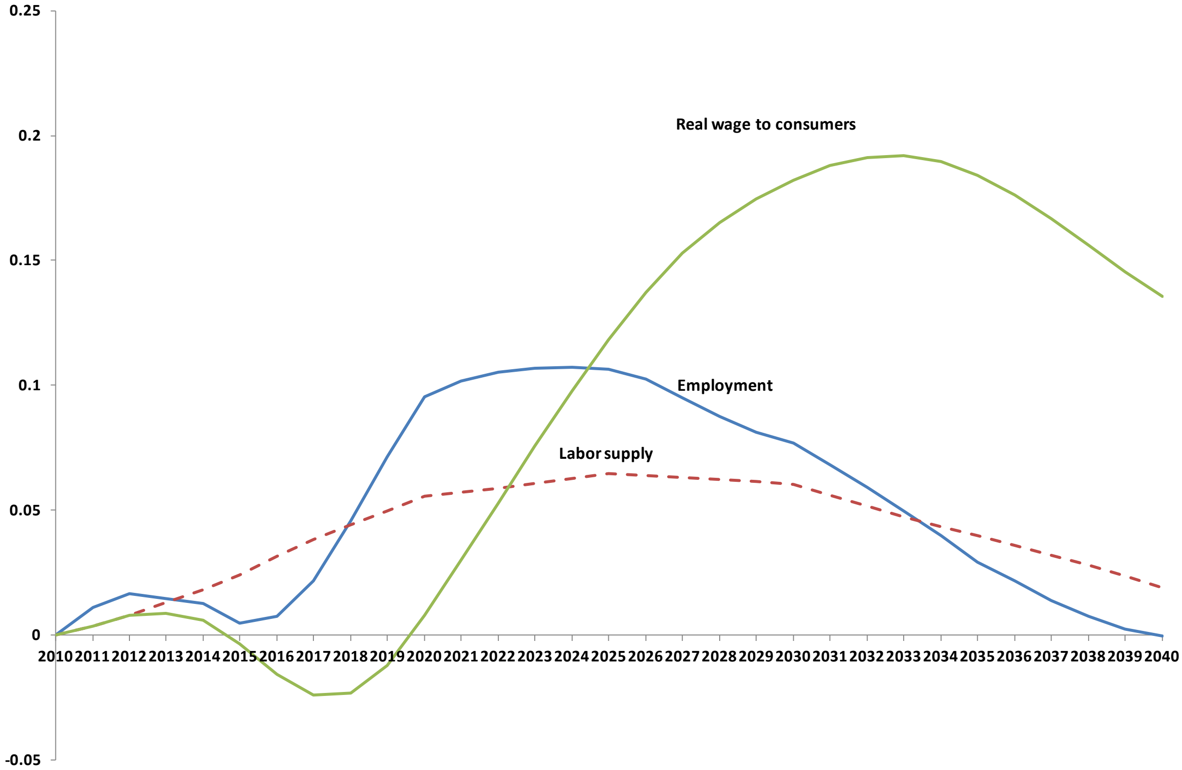


Chart 3.10. Trade variables: H&b expenditures financed by a petroleum tax (percentage deviations from baseline)

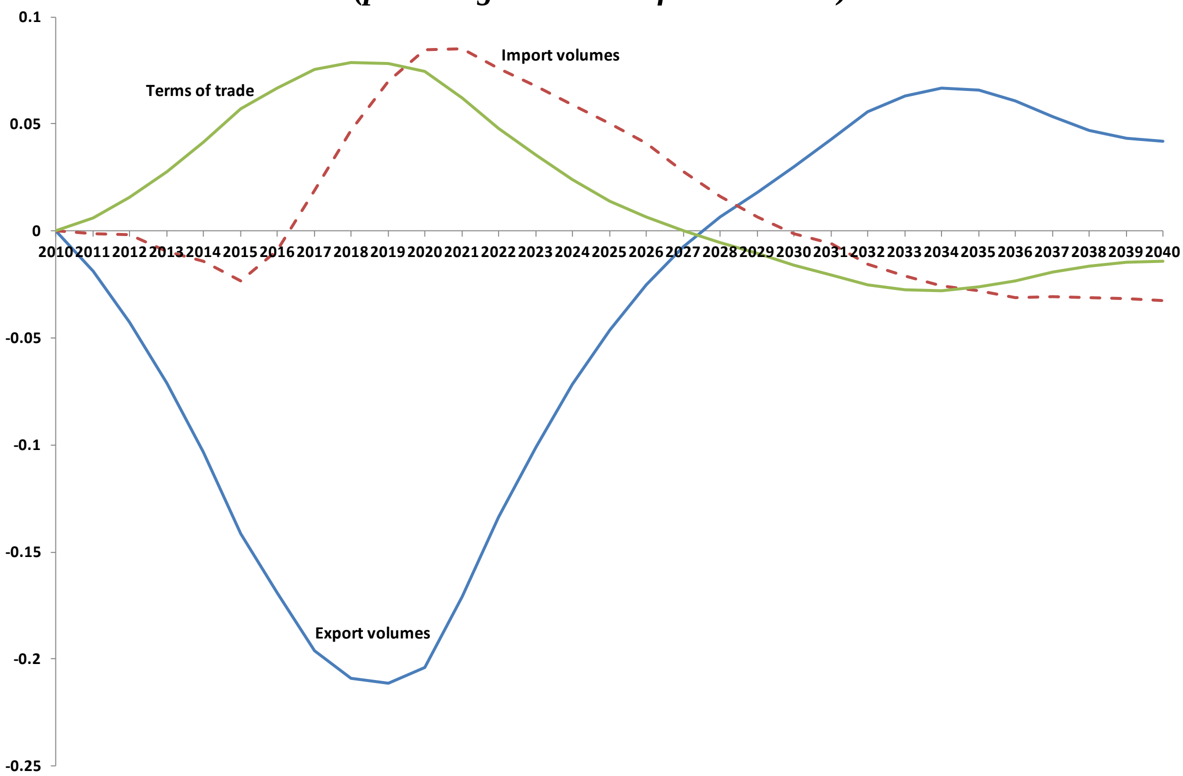
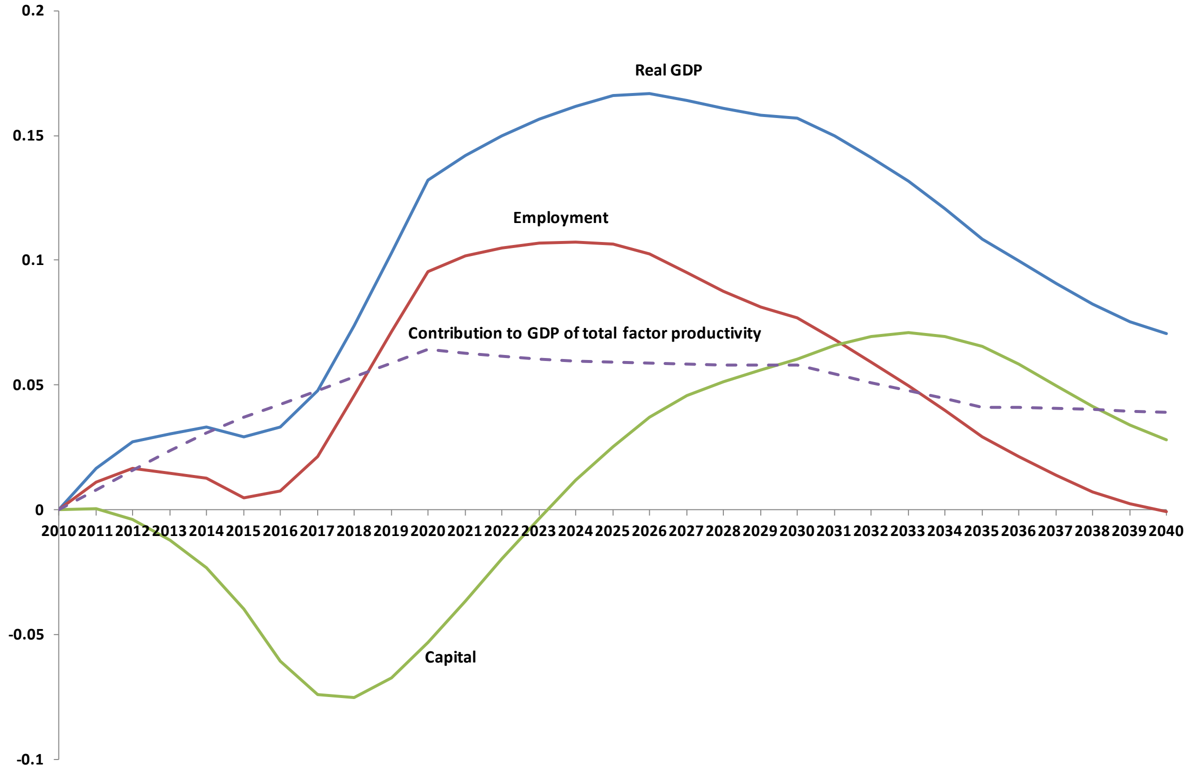


Chart 3.11. GDP and factor inputs: H&b expenditures financed by a petroleum tax (percentage deviations from baseline)



is sufficient to turn the investment and capital deviations negative in the early simulation years, see Chart 3.11.[9] Nevertheless, GDP increases: in terms of equation (3.3) the increases in A and L outweigh the decreases in K.

Between 2016 and 2020, the employment deviation under petroleum-tax financing grows quickly, Chart 3.9. 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 2.2) 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 3.9) 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.

There is nothing in this explanation of the petroleum-tax results that is specific to petroleum. Results similar to those in Charts 3.9 to 3.11 would be obtained in a simulation in which H&b expenditures are financed by a general tax on consumption.

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[9] Equation (3.4) can be revised to include the T effect: $\frac{Q}{P_i} = \frac{P_{gdp}}{P_i} * (1-T) * A * F_k(K/L)$.

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

Charts 3.12 to 3.14 repeat the welfare effects shown in Chart 3.2 for simulations 1 to 3, together with welfare effects calculated in sensitivity simulations in which time saving in transport does not affect labor supply. Under deficit financing, ruling out the labor supply response has almost no effect on the welfare implications of H&b expenditure. By contrast, when H&b expenditures are financed by lump-sum-taxes or petroleum-taxes, then ruling out the labor supply response noticeably reduces the simulated welfare gains of H&b expenditure.

In our simulations, an extra hour of work reduces leisure by an hour. An extra hour 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 Charts 3.13 and 3.14 for simulations in which extra H&b expenditures are not allowed to cause a deterioration in the public sector deficit. But this is not the case in Chart 3.12.

In simulations 4 to 6, ruling out the labor supply boost from H&b expenditures causes employment to follow lower paths than in simulations 1 to 3. This causes social security payments and other government benefits to households in simulations 4 to 6 to be higher than in simulations 1 to 3. In simulations 5 and 6 these extra government benefits do not stimulate consumption. Instead, they cause the lump-sum or petroleum-tax to be higher than in simulations 2 and 3 so that the public-sector deficit to GDP ratio can stay on its baseline path. In simulation 4, 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 simulation 4. 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 gap in Chart 3.12 between the welfare results for simulations 1 and 4. In simulation 4, there is a more rapid build-up of net foreign liabilities than in simulation 1. Eventually, the extra interest and dividend payments to foreigners start to exert a significant negative influence on household income and consumption.

4. Concluding remarks and directions for the future

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; safety and 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 all 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.

In this way we have created USAGE-Hwy as a tool for translating results from HERS into economic outcomes. 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.

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Chart 3.12. Aggregate Welfare under deficit financing (percentage deviations from baseline)

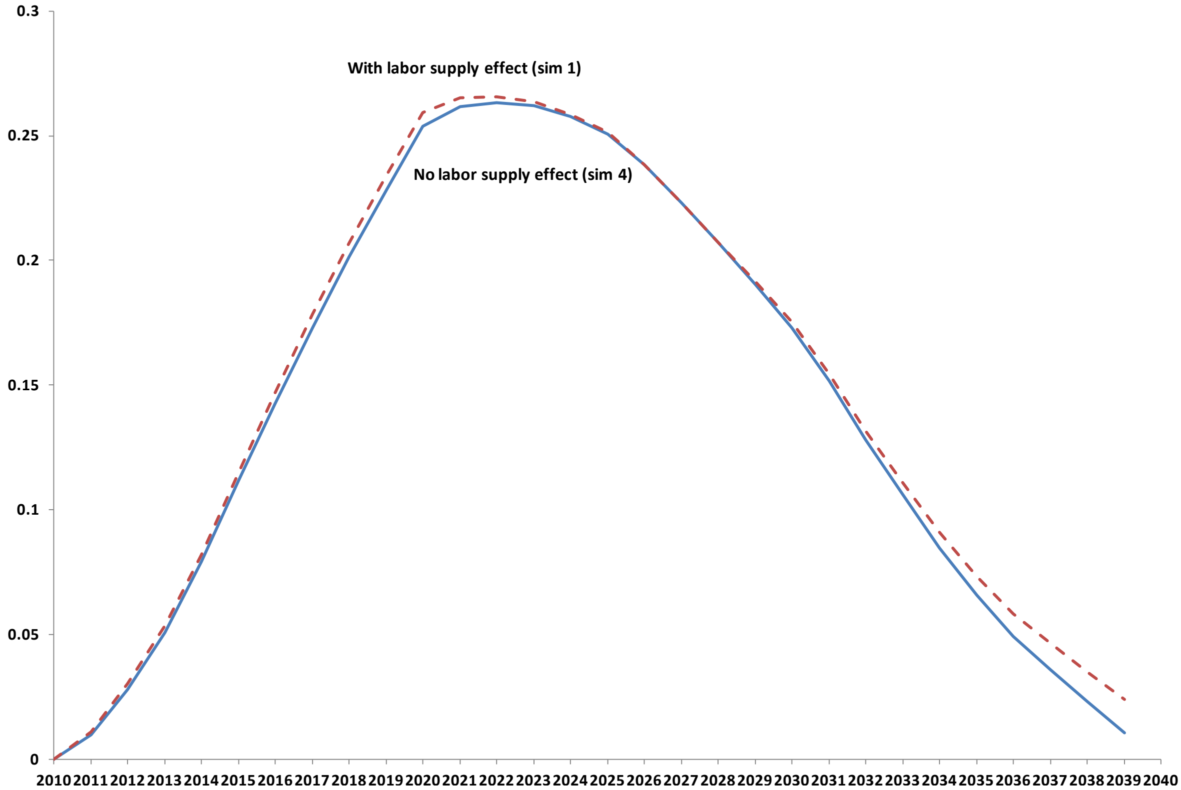


Chart 3.13. Aggregate Welfare under lump-sum-tax financing (percentage deviations from baseline)

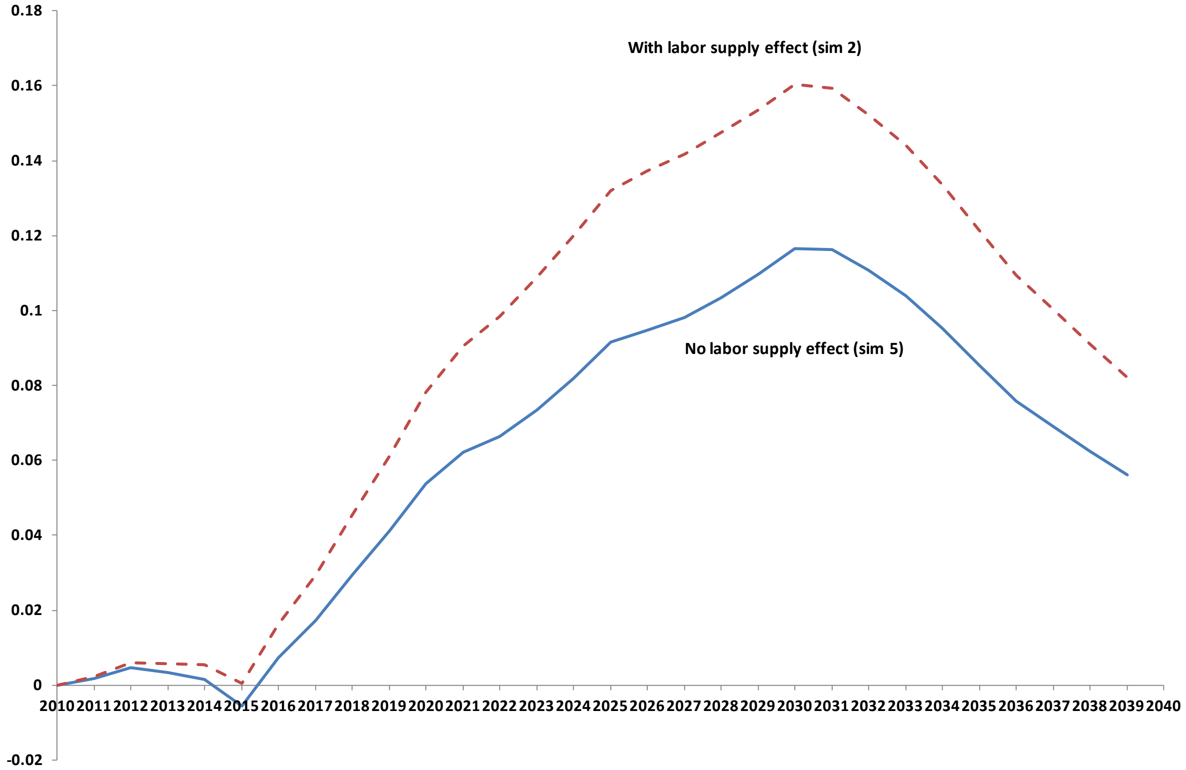
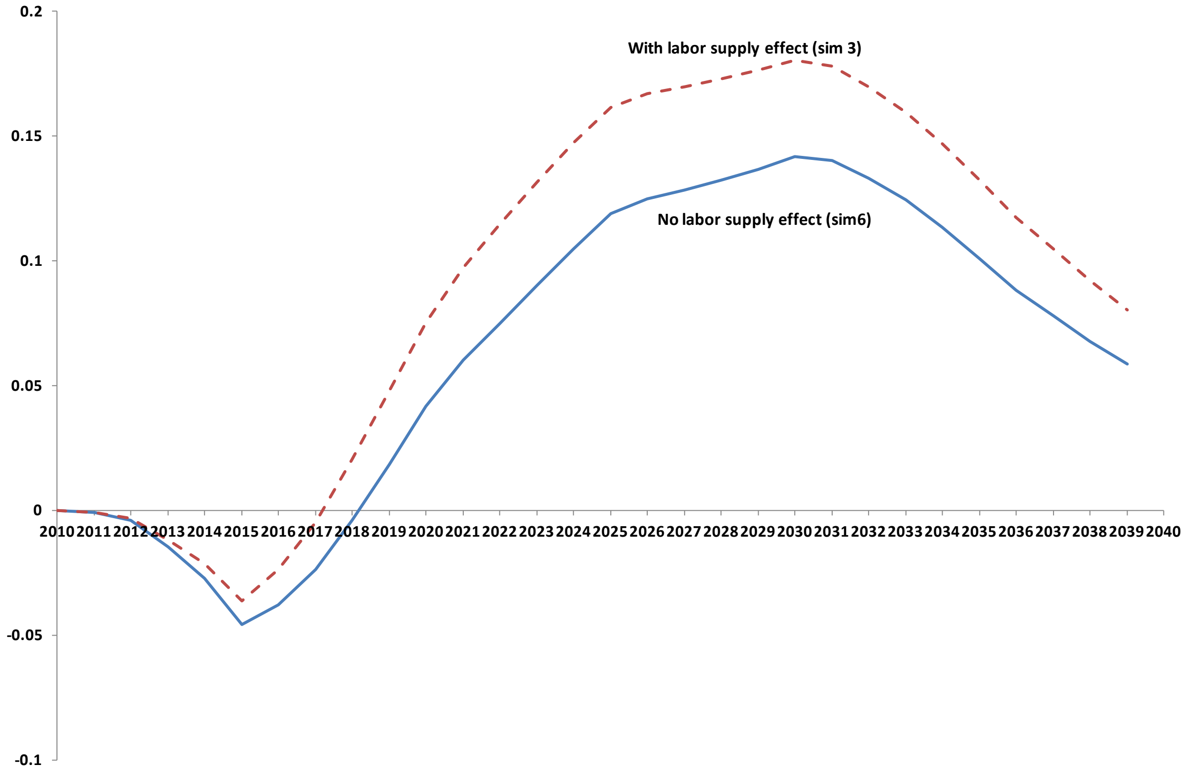


Chart 3.14. Aggregate Welfare under petroleum-tax financing (percentage deviations from baseline)



In this paper we have provided an illustrative application of USAGE-Hwy. We have translated HERS results for the effects of increased highway infrastructure expenditure into implications for macroeconomic variables including aggregate welfare, employment, exports, imports, private consumption, investment, government consumption, net foreign liabilities, average wage rates, labor supply and the public sector deficit. In future applications of USAGE-Hwy this list could be extended to include industry, regional and skill variables. These variables might assist in pinpointing bottleneck issues. For example, USAGE-Hwy results might throw light on the question of whether a highway project planned for a particular region could be supported by the skills available in the local labor force and construction industry.

Another direction in which USAGE-Hwy results could be extended is in sensitivity analysis. Here we provided sensitivity analysis on the link between travel-time saving and labor supply. Other sensitivity issues could be investigated. For example, to what extent do the results depend on the state of the business cycle assumed in the baseline? In the simulations in section 3, we assume that the economy is operating at normal levels of employment and capacity utilization. More favorable results for the effects of increased highway infrastructure expenditure could be expected if we had assumed a depressed state for the economy in the early years of the simulations.

However, in a model such as USAGE-Hwy sensitivity analysis must be used sparingly. USAGE-Hwy has many thousands of parameters and invokes a large range of assumptions about economic behaviour, all of which could be the subject of sensitivity tests. In these circumstances, it is necessary to understand the results in terms of back-of-the-envelope analyses which reveal the parameters and assumptions that are important for the particular results under scrutiny. Informed by back-of-the-envelope analysis, we can focus sensitivity tests on areas in which it is needed. Consequently in this paper we have used back-of-the-envelope arguments to reveal the key assumptions underlying our principal results.