Online Appendices: A Model of the Australian Housing Market

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March 2019

These appendices provide additional information to accompany Research Discussion Paper No 2019-01.

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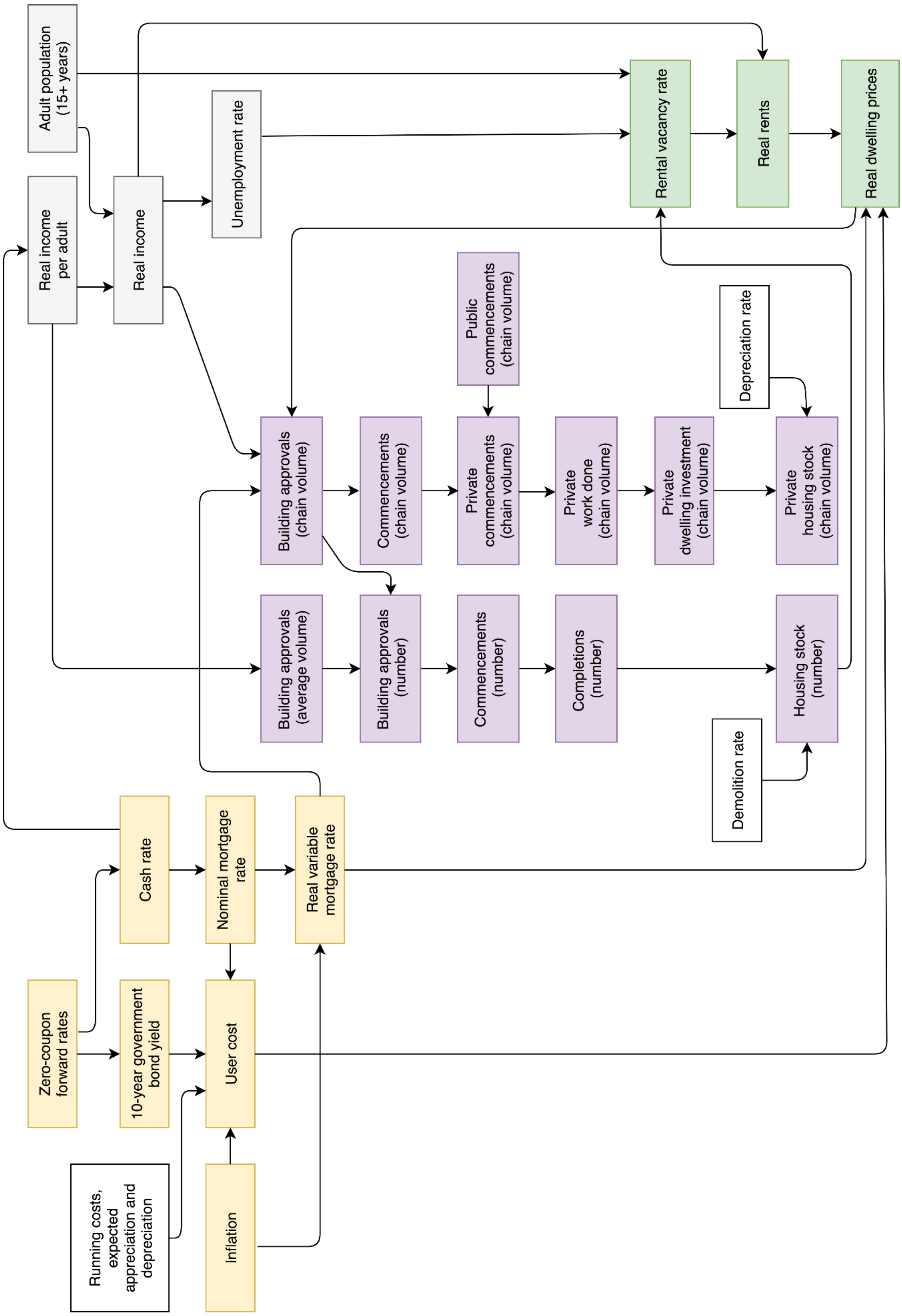
Appendix A: A Diagrammatic Overview of the Model

Figure A1: Detailed Model Overview



Appendix B: Housing Construction

There has been a reasonably stable long-run relationship between building approvals, commencements, work done, investment, and completions. As a building approval is required before construction can commence on a new dwelling, we start with estimates of approvals, then map these through to other construction variables. These relationships are shown by the purple boxes in Figure A1.

B.1 Residential Building Approvals

Building approvals feed into two separate chains of variables.

1. Constant price measures of approvals are used to estimate dwelling investment and the real value of the housing stock.

2. The number of new building approvals is used to estimate completions and the number of dwellings, which in turn, feed into estimates of the rental vacancy rate.

The different measures of building approvals (i.e. constant price and number) are related to each other by the average quality of new dwellings. The equations for the constant price measures of building approvals are discussed in Section 4.1 of the paper.

Number of approvals

We estimate separate equations for the constant price measures and average quality of approvals, then back out the number of approvals using the following identity:

$$APPNO_t = \frac{APP_t}{QUALITY_t}$$

where $APPNO$ is the number of approvals, APP is the chain volume measure of approvals, and $QUALITY$ is the quality, or average volume, of approvals. A key advantage of this approach (relative to directly estimating the number of approvals) is that the quality of approvals is much less volatile than the number of approvals, so it is easier to estimate. Relatedly, the number of approvals drives the cyclical variation in the constant price measures of approvals. Having separate equations for both the number and constant price measure of approvals could result in inconsistent estimates of the housing construction cycle.

Quality of approvals

We assume that the quality (or average volume) of approvals increases in line with real income per capita in the long run.

$$\Delta\left(quality_t\right) = -\lambda\left(quality_{t-1} - hhdy\_capita_{t-1} - \theta_t\right) + \Delta hhdy\_capita^* \quad \text{(B1)}$$

where *quality* is the average volume of dwelling approvals, *hhdy_capita* is real household disposable income per adult (15+ years), and $\Delta hhdy\_capita^*$ is steady-state growth of real income per adult. All variables are in natural logs.

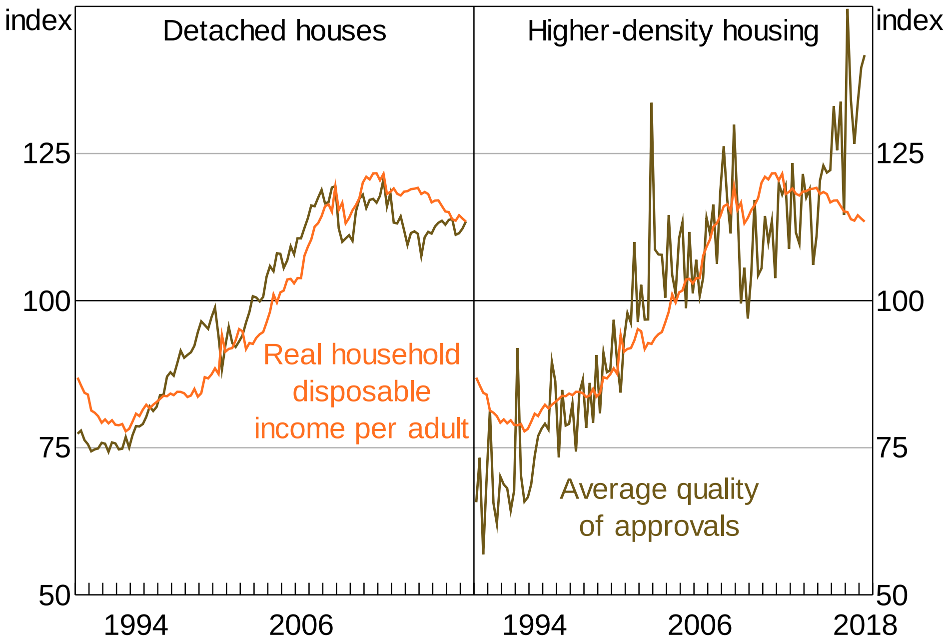
We have used simple assumptions for the two parameters in Equation (B1): λ and θ.

1. The speed of adjustment coefficient, λ, is set equal to the speed of adjustment for the constant price measure of approvals (Equation (1) in the paper). This ensures that the responses to income from Equation (1) and Equation (B1) are broadly consistent.

2. θ is the steady-state ratio of the average quality of approvals and real income per capita (in logs). We assume θ is equal to the average value of this log-ratio in the final two years of our sample. We calculate this average over a two-year period (as opposed to a longer horizon), so that θ is fairly responsive to recent data: while real income per adult and the average volume of approvals have grown at a similar rate in the long run (Figure B1), it is not clear that the ratio of these variables should be stationary.

Figure B1: Average Quality of Approvals and Real Income per Adult

Long-run average = 100



Source: ABS

This specification has a couple of important implications.

First, increases in real income per capita lead to an increase in the quality of new housing, but have little effect on the number of new dwellings. It is somewhat puzzling that changes in income per capita have little effect on the number of dwellings while changes in interest rates and housing prices have very large effects. However, this seems to be a feature of the data for Australia.

Second, the number of approvals grows at the same rate as the adult population in the long run. This implies that average household size will be stable. As discussed in Section 4.3 of the paper, a more complicated model might be able to model household size as decreasing with income and increasing with rent. This is left for future work.

Private and public building approvals

The previous estimates of residential building approvals do not distinguish between private and public approvals. This is not important for our estimates of the number of dwellings (which includes all additions to the housing stock), but it is an issue for our estimates of dwelling investment (which only includes the private sector).

For each component of commencements, we use an AR(4) in log levels to estimate the volume of public sector commencements. We then subtract public commencements from our previous estimates of total commencements to estimate private sector building commencements.

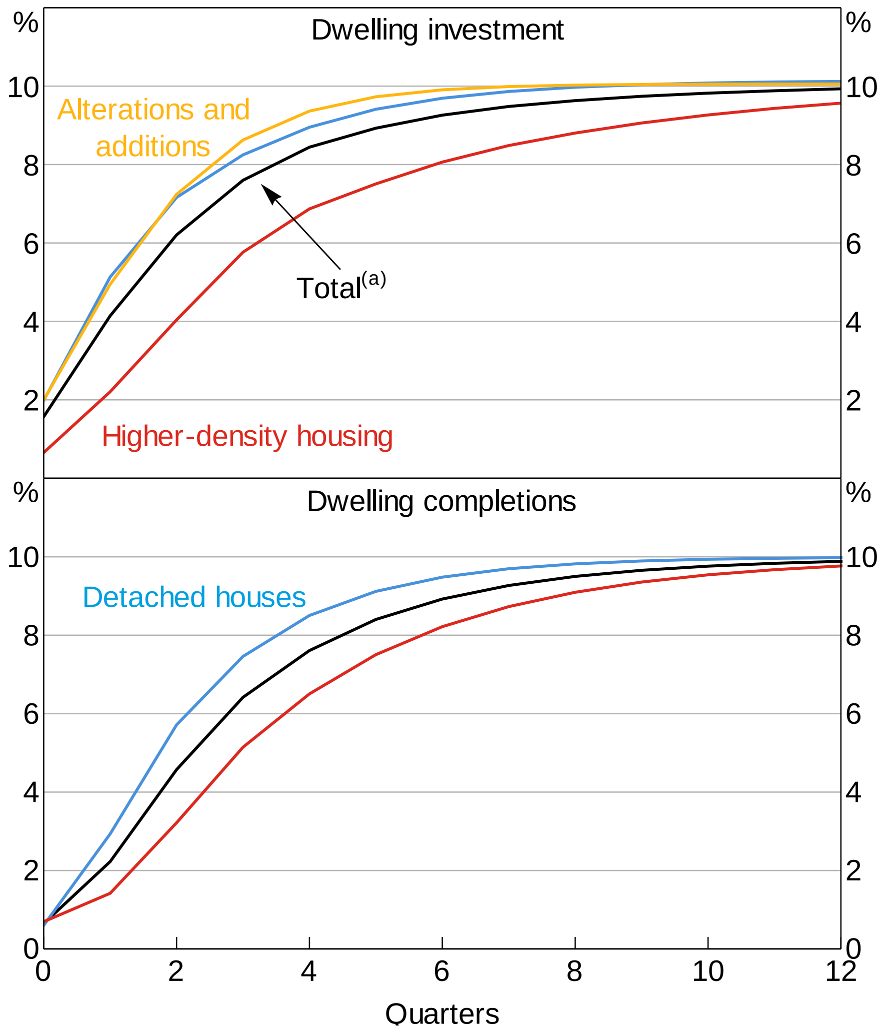
B.2 Construction Activity

Constant prices

We use single equation error correction models to map the volume of building approvals to commencements, then commencements to work done. We then assume growth of national accounts investment is equal to growth of work done. Separate equations are estimated for each component of housing construction. We have restricted the long-run elasticity in each of these equations to equal 1, so that approvals and investment grow at the same rate in the long run.

As shown in Figure B2, around 50 per cent of the investment in detached houses is estimated to be completed within one quarter of the building approval, and around 90 per cent within four quarters. Construction times on higher-density housing are likely to be much more variable. Nevertheless, the data suggest that most projects commence shortly after a building approval is issued and, on average, around 70 per cent of the work done on projects is completed within four quarters of the approval.

Figure B2: Responses to a Sustained 10 Per Cent Increase in Approvals



Note: (a) Weighted by shares in national accounts dwelling investment

Sources: ABS; Authors' calculations

Number

Similar to the constant price measures of construction activity, we use single equation error correction models to map the number of building approvals to commencements, then commencements to completions.

We estimate that for detached houses, around 30 per cent of completions occur within one quarter of the building approval, and around 85 per cent within four quarters. For higher-density housing, around 65 per cent of dwellings are completed within four quarters of the approval.

B.3 Dwelling Stock

Constant prices

Quarterly estimates of the constant price dwelling stock are constructed by combining annual data on the dwelling stock (from the Australian System of National Accounts (ASNA)) with quarterly estimates of net additions to the housing stock. Net additions to the housing stock are based on estimates of dwelling investment and the replacement rate (which includes both demolitions and depreciation). Specifically, in quarters where national accounts data are not available, we use the equation below to calculate estimates of the dwelling stock.

$$stock_t = stock_{t-1} + investment_t \left(1 - replacement\_rate_t\right)$$

The replacement rate is estimated by comparing the dwelling stock in two successive releases of the ASNA and total dwelling investment during this period. That is, the difference between total gross additions to the dwelling stock and the actual change in the dwelling stock equals the loss from depreciation and demolitions.

Number of dwellings

The process for estimating the number of dwellings is similar to that for the constant price measure of the dwelling stock (see above). The ABS Census provides data on the number of dwellings in Australia every five years.[1] These data are used as a benchmark for our quarterly estimates of the number of dwellings. Specifically, we use the equation below to estimate the number of dwellings for intercensal periods.

$$stock\_number_t = stock\_number_{t-1} + completions_t \left(1 - demolition\_rate_t\right)$$

The number of demolitions is estimated by comparing the dwelling stock measured in two successive Census surveys and the number of completions during this period. That is, the difference between total gross additions to the dwelling stock and the actual change in the dwelling stock equals demolitions. To apportion the total between Census years, we assume that the number of demolitions in each quarter is proportional to the number of completions in that quarter. The intuition being that the greater the number of completions in a given period, the greater the number of demolitions needed to make room for these new homes. After the 2016 Census, we assume the demolition rate is unchanged at 8.3 per cent of completions.

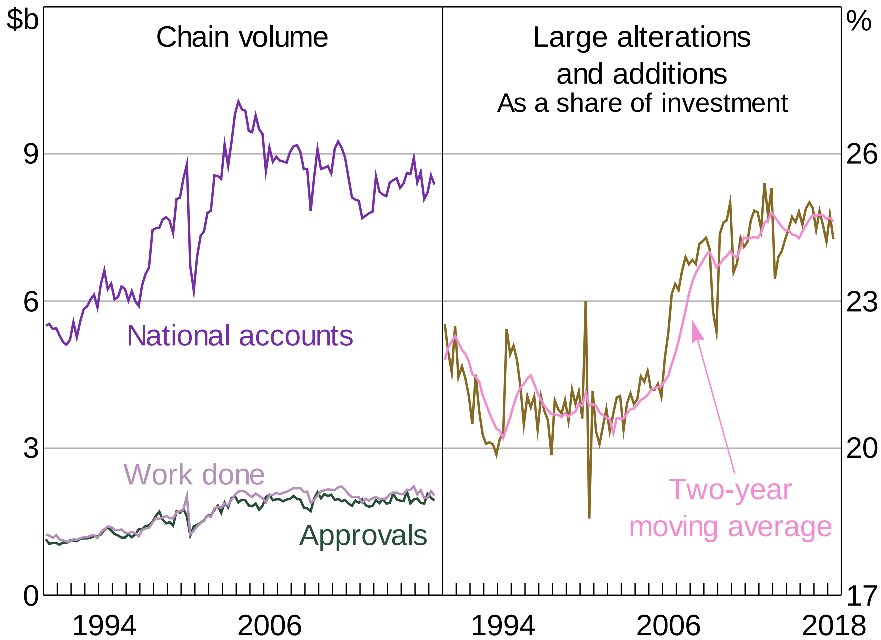
B.4 Coverage of Alterations and Additions Data

The ABS publishes data on building approvals, commencements and work done for large alterations and additions (valued over $10,000). However, expenditure on large alterations and additions only accounts for around a quarter of total spending on alterations and additions (Figure B3).[2] Large alterations and additions share of total alterations and additions investment has also changed over time, increasing from around 21 per cent in the early 2000s.

1 The dwelling stock is defined as the sum of all occupied and unoccupied dwellings from the Census, less caravans, house boats, cabins and improvised homes.

2 The ABS use estimates from the Construction Industry Survey (CIS) as a benchmark for the national accounts measure of alterations and additions investment. This survey is conducted every six to seven years. To estimate quarterly investment between each CIS, the ABS primarily use estimates of work done on large alterations and additions. Information from the Household Expenditure Survey (HES) is also used as a crosscheck on these estimates.

Figure B3: Alterations and Additions Activity



Source: ABS

This raises an issue for our estimates of alteration and additions approvals. Without any adjustments to the data, this equation would estimate the effect of interest rates and dwelling prices on large alterations and additions, rather than total alterations and additions.

To address this issue, we have scaled the data on large alterations and additions approvals, commencements, and work done, so that the levels of these data are representative of total alterations and additions investment. The data have been scaled using a two-year moving average of the ratio of work done to the national accounts measure of alterations and additions investment.

$$\hat{y}_t = y_t \left(\frac{1}{8} \sum_{i=1}^{8} \frac{wd_{t-i+1}}{na_{t-i+1}} \right)^{-1}$$

where y is {approvals, commencements, work done} for large alterations and additions, $\hat{y}$ is the scaled data, wd is work done on large alterations and additions, and na is the national accounts measure of total alterations and additions investment.

Appendix C: Baseline Forecast

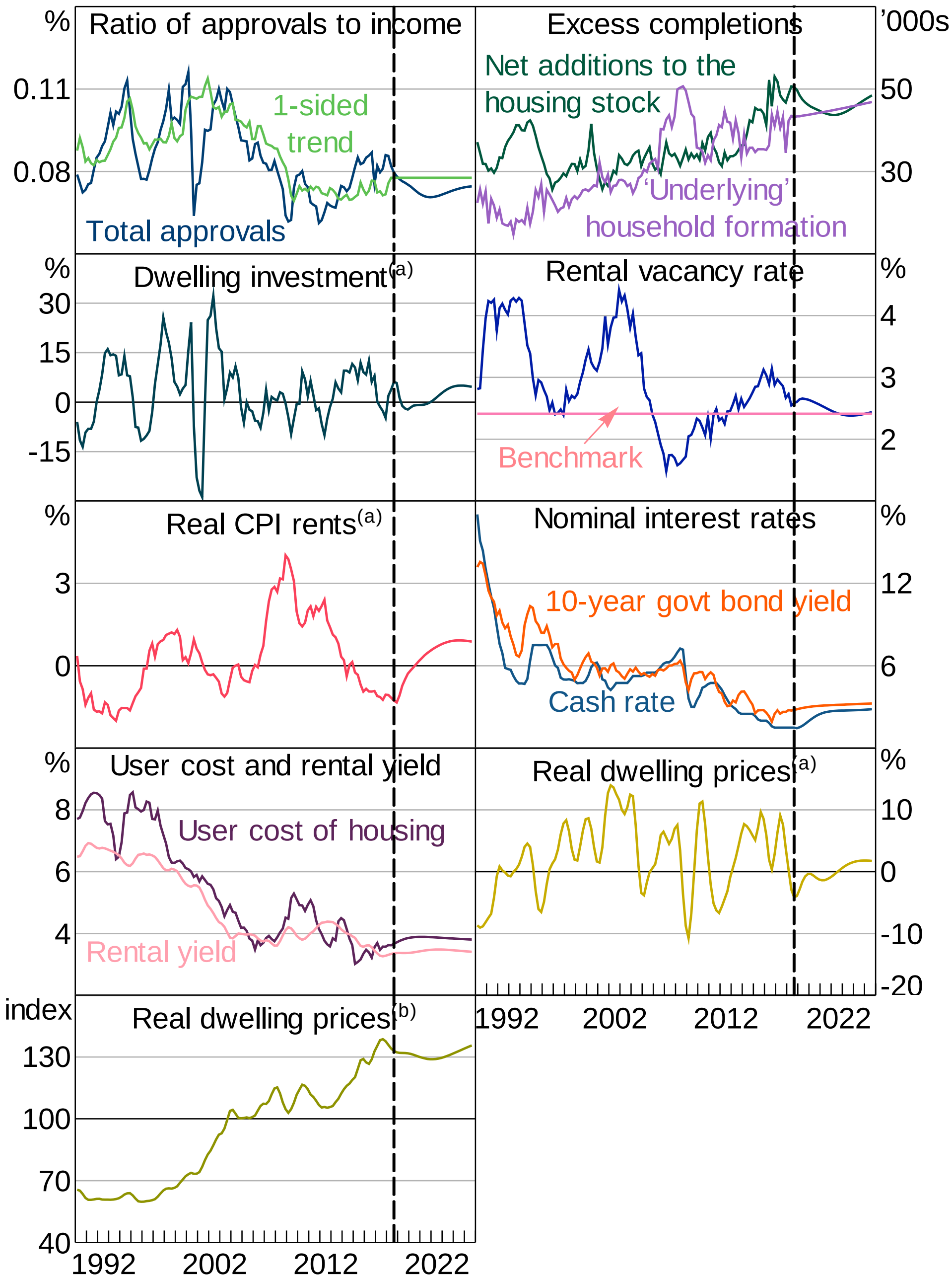
Our model can be used for conditional forecasting. Forecasts starting in 2018:Q3 are shown in Figure C1. These forecasts should not be confused with the RBA's official forecasts published in the *Statement on Monetary Policy* (*SMP*). Our forecasts are only one of many inputs to the *SMP*, which also reflects other models, leading indicators, liaison and judgement. To construct the forecasts we assume that interest rates evolve in line with forward rates. Real income and population growth are projected to grow at their recent average growth rates, according to autoregressions. We make similar neutral assumptions for other exogenous variables. We implicitly assume that policy with respect to zoning or taxes is unchanged. Then we solve the model.

These forecasts form the baseline for some of the scenarios considered in Section 5 of the paper. They are also of interest in their own right. Although the forecasts shown above quickly become out of date, the code used to generate them is available with the supplementary information for this paper on the RBA website, so anyone with access to the data can update them (series on vacancies and prices need to be purchased). These forecasts use data available at the end of October 2018. More recent forecasts show smaller increases in the cash rate and larger reductions in housing prices and construction activity.

In the past few years, construction activity has been moderately strong, relative both to its trend ratio to income (top left panel) and to exogenous household formation (top right). That reflects responses to previous falls in interest rates and rises in house prices. As those effects fade away, various measures of construction (the first three panels) and the vacancy rate (second row, right) decline. Real rents (third row, left) stop falling and gradually return to trend growth.

Over the next two years, the cash rate and bond yields rise gradually, in line with the yield curve (third row, right), which boosts the user cost of housing (fourth row, left). Real dwelling prices (last two panels) continue to decline, reflecting momentum and rising interest rates.

Figure C1: Forecast



Notes: Dashed vertical line represents forecasts beginning in 2018:Q3

(a) Year-ended growth

(b) 2005 average = 100

Sources: ABS; Authors' calculations; Corelogic; RBA; REIA

Appendix D: Variable List

Table D1: Construction Variables

(*continued next page*)

Mnemonic	Component	Variable	Unit of measurement	Sector	Appendix E equation	ABS Cat No
baaavol	Alterations and additions	Building approvals	Chain volume	Total	3	8731.0 – Building Approvals, Australia
bahouseavol	Detached houses	Building approvals	Average quality (bahousevol /bahouseno)	Total	43	8731.0
bahouseno	Detached houses	Building approvals	Number	Total	44	8731.0
bahousevol	Detached houses	Building approvals	Chain volume	Total	1	8731.0
baotheravol	Higher-density housing	Building approvals	Average quality (baothervol /baotherno)	Total	45	8731.0
baotherno	Higher-density housing	Building approvals	Number	Total	46	8731.0
baothervol	Higher-density housing	Building approvals	Chain volume	Total	2	8731.0
batotalno	Total	Building approvals	Number	Total	54	8731.0
batotalvol	Total	Building approvals	Chain volume	Total	53	8731.0
caavol	Alterations and additions	Commencements	Chain volume	Total	10	8752.0 – Building Activity, Australia
caavol_private	Alterations and additions	Commencements	Chain volume	Private	51	8752.0
caavol_public	Alterations and additions	Commencements	Chain volume	Public	13	8752.0
chouseno	Detached houses	Commencements	Number	Total	4	8752.0
chouseno_private	Detached houses	Commencements	Number	Private		8752.0
chousevol	Detached houses	Commencements	Chain volume	Total	8	8752.0
chousevol_private	Detached houses	Commencements	Chain volume	Private	47	8752.0
chousevol_public	Detached houses	Commencements	Chain volume	Public	11	8752.0
cotherno	Higher-density housing	Commencements	Number	Total	5	8752.0
cotherno_private	Higher-density housing	Commencements	Number	Private		8752.0
cothervol	Higher-density housing	Commencements	Chain volume	Total	9	8752.0
cothervol_private	Higher-density housing	Commencements	Chain volume	Private	49	8752.0

Table D1: Construction Variables
(*continued*)

Mnemonic	Component	Variable	Unit of measurement	Sector	Appendix E equation	ABS Cat No
cothervol_public	Higher-density housing	Commencements	Chain volume	Public	12	8752.0
ctotalno	Total	Commencements	Number	Total		8752.0
ctotalno_private	Total	Commencements	Number	Private		8752.0
ctotalvol	Total	Commencements	Chain volume	Total		8752.0
ctotalvol_private	Total	Commencements	Chain volume	Private		8752.0
comphouseno	Detached houses	Completions	Number	Total	6	8752.0
comphouseno_private	Detached houses	Completions	Number	Private		8752.0
compotherno	Higher-density housing	Completions	Number	Total	7	8752.0
compotherno_private	Higher-density housing	Completions	Number	Private		8752.0
ipd_aa	Alterations and additions	Investment deflator	Index	Private		ABS special request data
ipd_house	Detached houses	Investment deflator	Index	Private		ABS special request data
ipd_other	Higher-density housing	Investment deflator	Index	Private		ABS special request data
ipd_nanew	New and used	Investment deflator	Index	Private		5206.0 – Australian National Accounts: National Income, Expenditure and Product
ipd_natdi	Total	Investment deflator	Index	Private		5206.0
naaavol	Alterations and additions	Dwelling investment	Chain volume	Private	52	ABS special request data
nahousevol	Detached houses	Dwelling investment	Chain volume	Private	48	ABS special request data
naothervol	Higher-density housing	Dwelling investment	Chain volume	Private	50	ABS special request data
nanewvol	New and used (i.e. detached houses and higher-density housing	Dwelling investment	Chain volume	Private	55	5206.0
natdi	Total	Dwelling investment	Chain volume	Private	56	5206.0
wdaavol	Alterations and additions	Work done	Chain volume	Private	16	8752.0
wdhousevol	Detached houses	Work done	Chain volume	Private	14	8752.0
wdothervol	Higher-density housing	Work done	Chain volume	Private	15	8752.0
wdnewvol	New and used	Work done	Chain volume	Private		8752.0

Table D2: Non-construction Data

(*continued next page*)

Mnemonic	Variable	Appendix E equation	Source	Details
cash	Interbank overnight cash rate	22	RBA statistical table F1.1 Interest Rates and Yields – Money Market	Quarter average
cash_exp	Interbank overnight cash rate (includes market path for simulations)		RBA statistical table F1.1 RBA statistical table F17 Zero-coupon Interest Rates – Analytical Series – 2009 to Current	Quarter average
inf_exp	Expected inflation	29	ABS Cat No 6401.0 – Consumer Price Index, Australia RBA statistical table G3 Inflation Expectations	From 1986:Q3 we use quarterly averages of 10-year bond break-even rates; before this the data are spliced using five-year average growth of headline CPI
inc	Household disposable income		ABS Cat No 5206.0	Before interest adjustments, including unincorporated firms
rinc	Real household disposable income	59	ABS Cat Nos 5206.0 and 6401.0	'inc' deflated using seasonally adjusted trimmed mean CPI ('tcpi')
rinc_per_capita	Real household disposable income per adult (15+ years)	21	ABS Cat Nos 5206.0, 6401.0 and 6202.0 – Labour Force, Australia	'rinc' divided by adult population ('wap')
i_10y_bond	10-year government bond yield	25	RBA statistical table F2.1 Capital Market Yields – Government Bonds RBA historical statistical table F2 Capital Market Yields – Government Bonds (monthly)	Yields on Australian government bonds, 10 years maturity; quarter average
ndp	Nominal housing prices	19	CoreLogic – Home value index	All dwellings, hedonic, weighted eight capital cities; quarter average Available by subscription at <https://www.corelogic.com.au/>
rdp	Real housing prices	19	ABS Cat No 6401.0; CoreLogic	'ndp' deflated using trimmed mean CPI ('tcpi')
rent_cpi	CPI rents	18	ABS Cat No 6401.0	
rrent	Real CPI rents	36	ABS Cat No 6401.0	'rent_cpi' deflated using seasonally adjusted trimmed mean CPI ('tcpi')
stock	Housing stock, chain volume	40	ABS Cat Nos 5206.0 and 5204.0 – Australian System of National Accounts; authors' calculations	See Appendix B.3
stock_no	Housing stock, number	39	ABS Cat No 8752.0; ABS Census (various years); authors' calculations	See Appendix B.3
depreciation_rate	Depreciation rate	42	Authors' calculations	See Appendix B.3
demolition_rate	Demolition rate	41	Authors' calculations	See Appendix B.3

Table D2: Non-construction Data

(*continued*)

Mnemonic	Variable	Appendix E equation	Source	Details
tcpi	Trimmed mean CPI	34	ABS Cat No 6401.0	Seasonally adjusted; excluding interest and tax changes; spliced using headline CPI for periods prior to 1982:Q1
uc	User cost of housing	26	Fox and Tulip (2014)[(a)]; authors' calculations	See footnote 11 in the paper
uc_appreciation	Expected housing appreciation	30	Fox and Tulip (2014)[(a)]	Updated, then constant from 2017:Q3
uc_depreciation	Expected housing depreciation	31	Fox and Tulip (2014)[(a)]	Updated, then constant from 2017:Q3
uc_running_cost	Running cost	33	Fox and Tulip (2014)[(a)]	Updated, then constant from 2017:Q3
uc_stamp_duty	Stamp duty cost		Fox and Tulip (2014)[(a)]	Updated, then constant from 2017:Q3
uc_transaction_cost	Transaction cost	32	Fox and Tulip (2014)[(a)]	Updated, then constant from 2017:Q3
ur	Unemployment rate	62	ABS Cat No 6202.0	
vacancy	Rental vacancy rate	17	Real Estate Institute of Australia (REIA)	Average of mainland state capital cities (excluding Adelaide), weighted by dwelling stock (number of dwellings) Available by subscription at <https://reia.asn.au/product/reia-reports-subscription-remf>
vmr	Variable mortgage rate	23	RBA statistical table F5 Lending Rates	From 2004:Q3 onwards, the series is the discounted variable mortgage rate for owner-occupier housing; for periods prior to 2004:Q3, the data are spliced using the standard variable mortgage rate for owner-occupier housing; further details on these series are available in the notes section of RBA statistical table F5
vmr_exp	Expected mortgage rate	28		From 1997: $vmr\_exp = vmr + (i\_10y\_bond - cash) - (\overline{i\_10y\_bond - cash})$ where the superscript bar represents the sample mean; from 1982 to 1997 we assume the expected variable mortgage rate is a constant spread (equal to its 1997 level) to the 10-year bond yield
rvmr_exp	Real expected mortgage rate	27		'vmr_exp' deflated using expected inflation ('inf_exp')
wap	Adult (15+ years) population	20	ABS Cat No 6202.0	
yield	Rental yield	37		'rent_cpi'/'ndp', adjusted to have the same mean as matched sample estimate

Note: (a) R Fox and P Tulip (2014), 'Is Housing Overvalued?', RBA Research Discussion Paper No 2014-06

Appendix E: Equations

E.1 Estimated Equations

E1: Detached housing approvals (constant prices)

Signal equation: dlog(bahousevol)-@mean(dlog(bahousevol)) = c(1)*(log(bahousevol(-1)/rinc(-1))) + c(3)*(dlog(bahousevol(-1))-@mean(dlog(bahousevol(-1)))) + c(4)*(dlog(rdp(-1))-@mean(dlog(rdp(-1)))) + c(6)*gst + c(7)*gst(-1) + c(8)*gst(-2) + c(9)*(d(rvmr(-1))) + c(10)*(d(rvmr(-2))) + c(11)*(d(rvmr(-3))) + sv1 + e1

State Equation: sv1 = sv1(-1) + e2

Sspace: SS_HOUSE
Method: Maximum likelihood (BFGS / Marquardt steps)
Date: 12/21/18 Time: 14:14
Sample: 1987Q1 2018Q2
Included observations: 126
User prior mean: MPRIOR_HOUSE
User prior variance: VPRIOR_HOUSE
Convergence achieved after 26 iterations
Coefficient covariance computed using outer product of gradients

	Coefficient	Std. Error	z-Statistic	Prob.
C(1)	-0.100361	0.048104	-2.086352	0.0369
C(3)	0.193319	0.091692	2.108346	0.0350
C(4)	0.696450	0.327964	2.123553	0.0337
C(6)	-0.292142	0.302617	-0.965387	0.3344
C(7)	-0.332333	0.290471	-1.144118	0.2526
C(8)	0.125014	0.276530	0.452083	0.6512
C(9)	-0.040479	0.008707	-4.648956	0.0000
C(10)	-0.016503	0.012830	-1.286257	0.1984
C(11)	-0.004935	0.012121	-0.407153	0.6839
C(111)	-0.040104	0.002944	-13.62391	0.0000
C(112)	-0.003758	0.002652	-1.416771	0.1565
	Final State	Root MSE	z-Statistic	Prob.
SV1	0.106484	0.012567	8.473480	0.0000

Log likelihood	219.1583	Akaike info criterion	-3.304100
Parameters	11	Schwarz criterion	-3.056488
Diffuse priors	0	Hannan-Quinn criter.	-3.203503

E2: Higher-density housing approvals (chain volume)

Signal equation: dlog(baothervol)-@mean(dlog(baothervol)) = c(1)*(log(baothervol(-1)/rinc(-1))) + c(3)*(dlog(baothervol(-1))-@mean(dlog(baothervol(-1)))) + c(4)*(dlog(baothervol(-2))-@mean(dlog(baothervol(-2)))) + c(5)*gst(-1) + c(6)*gst + c(7)*(dlog(rdp(-1))-@mean(dlog(rdp(-1)))) + c(8)*(dlog(rdp(-2))-@mean(dlog(rdp(-2)))) + c(11)*d(rvmr(-4)) + c(12)*d(rvmr(-5)) + c(13)*d(rvmr(-6)) + sv1 + e1

State Equation: sv1 = sv1(-1) + e2

Sspace: SS_OTHER
Method: Maximum likelihood (BFGS / Marquardt steps)
Date: 12/21/18 Time: 14:15
Sample: 1987Q1 2018Q2
Included observations: 126
User prior mean: MPRIOR_OTHER
User prior variance: VPRIOR_OTHER
Convergence achieved after 21 iterations
Coefficient covariance computed using outer product of gradients

	Coefficient	Std. Error	z-Statistic	Prob.
C(1)	-0.218119	0.142448	-1.531222	0.1257
C(3)	-0.359422	0.118268	-3.039046	0.0024
C(4)	-0.235235	0.099542	-2.363170	0.0181
C(5)	-0.352351	2.084274	-0.169052	0.8658
C(6)	-0.134336	2.282680	-0.058850	0.9531
C(7)	2.865936	1.198789	2.390693	0.0168
C(8)	0.135682	1.277500	0.106209	0.9154
C(11)	-0.047596	0.040156	-1.185266	0.2359
C(12)	-0.019440	0.039047	-0.497867	0.6186
C(13)	-0.040988	0.036529	-1.122076	0.2618
C(111)	-0.127044	0.010181	-12.47890	0.0000
C(112)	0.012171	0.013181	0.923346	0.3558

	Final State	Root MSE	z-Statistic	Prob.
SV1	0.176248	0.040275	4.376168	0.0000

Log likelihood	74.64281	Akaike info criterion	-0.994330
Parameters	12	Schwarz criterion	-0.724208
Diffuse priors	0	Hannan-Quinn criter.	-0.884588

E3: Alterations and additions approvals (chain volume)

Signal equation: dlog((baaavol))-@mean(dlog((baaavol))) = c(1)*(log((baaavol(-1))/rinc(-1))) + c(2)*(dlog((baaavol(-1)))-@mean(dlog((baaavol(-1))))) + c(4)*(dlog(rdp(-1))-@mean(dlog(rdp(-1)))) + c(5)*(dlog(rdp(-2))-@mean(dlog(rdp(-2)))) + c(6)*gst + c(7)*gst(-1) + c(8)*d(rvmr(-1))+ c(9)*d(rvmr(-2)) + c(10)*d(rvmr(-3)) + sv1 + e1

State Equation: sv1 = sv1(-1) + e2

Sspace: SS_AA
Method: Maximum likelihood (BFGS / Marquardt steps)
Date: 12/21/18 Time: 14:15
Sample: 1987Q1 2018Q2
Included observations: 126
User prior mean: MPRIOR_AA
User prior variance: VPRIOR_AA
Convergence achieved after 23 iterations
Coefficient covariance computed using outer product of gradients

	Coefficient	Std. Error	z-Statistic	Prob.
C(1)	-0.182937	0.096898	-1.887927	0.0590
C(2)	-0.235186	0.092095	-2.553729	0.0107
C(4)	0.540372	0.355093	1.521776	0.1281
C(5)	0.237203	0.409203	0.579671	0.5621
C(6)	-0.094603	0.406522	-0.232712	0.8160
C(7)	-0.297929	0.357951	-0.832317	0.4052
C(8)	-0.010476	0.012883	-0.813157	0.4161
C(9)	-0.012689	0.015948	-0.795629	0.4262
C(10)	-0.013542	0.015700	-0.862554	0.3884
C(111)	-0.045972	0.003840	-11.97026	0.0000
C(112)	0.008298	0.004553	1.822503	0.0684
	Final State	Root MSE	z-Statistic	Prob.
SV1	0.175294	0.020432	8.579404	0.0000

Log likelihood	196.5964	Akaike info criterion	-2.945975
Parameters	11	Schwarz criterion	-2.698363
Diffuse priors	0	Hannan-Quinn criter.	-2.845378

E4: Detached housing commencements (number)

Dependent Variable: DLOG(CHOUSENO)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1988Q1 2018Q2
Included observations: 122

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.029263	0.003474	-8.423945	0.0000
LOG(BAHOUSENO(-1))-LOG(CHOUSENO(-1))	0.942813	0.067582	13.95060	0.0000
DLOG(BAHOUSENO)	0.500654	0.048050	10.41949	0.0000
GST	0.037435	0.031027	1.206553	0.2300
GST(-1)	-0.151889	0.032909	-4.615442	0.0000

R-squared	0.875946	Mean dependent var	0.001504
Adjusted R-squared	0.871705	S.D. dependent var	0.079474
S.E. of regression	0.028466	Akaike info criterion	-4.240084
Sum squared resid	0.094807	Schwarz criterion	-4.125165
Log likelihood	263.6451	Hannan-Quinn criter.	-4.193407
F-statistic	206.5345	Durbin-Watson stat	1.968129
Prob(F-statistic)	0.000000		

E5: Higher-density housing commencements (number)

Dependent Variable: DLOG(COTHERNO)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1988Q1 2018Q2
Included observations: 122

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.068396	0.009727	-7.031357	0.0000
LOG(BAOTHERNO(-1))-LOG(COTHERNO(-1))	0.872102	0.078301	11.13781	0.0000
DLOG(BAOTHERNO)	0.555883	0.055985	9.929168	0.0000
GST(-1)	-0.115966	0.076289	-1.520094	0.1312

R-squared	0.617786	Mean dependent var	0.011185
Adjusted R-squared	0.608069	S.D. dependent var	0.118717
S.E. of regression	0.074322	Akaike info criterion	-2.328587
Sum squared resid	0.651800	Schwarz criterion	-2.236652
Log likelihood	146.0438	Hannan-Quinn criter.	-2.291246
F-statistic	63.57588	Durbin-Watson stat	1.987865
Prob(F-statistic)	0.000000		

E6: Detached housing completions (number)

Dependent Variable: DLOG(COMPHOUSENO)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1988Q1 2018Q2
Included observations: 122

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.003440	0.003754	-0.916198	0.3614
LOG(COMPHOUSENO(-1))-LOG(CHOUSENO(-1))	-0.413561	0.037358	-11.07036	0.0000
GST	0.084368	0.042668	1.977293	0.0504
GST(-1)	-0.092786	0.049826	-1.862187	0.0651
DLOG(CHOUSENO)	0.125903	0.057978	2.171558	0.0319

R-squared	0.592003	Mean dependent var	0.002075
Adjusted R-squared	0.578055	S.D. dependent var	0.062532
S.E. of regression	0.040619	Akaike info criterion	-3.529051
Sum squared resid	0.193037	Schwarz criterion	-3.414132
Log likelihood	220.2721	Hannan-Quinn criter.	-3.482375
F-statistic	42.44173	Durbin-Watson stat	2.580016
Prob(F-statistic)	0.000000		

E7: Higher-density housing completions (number)

Dependent Variable: DLOG(COMPOTHERNO)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1988Q1 2018Q2
Included observations: 122

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.017681	0.009958	-1.775475	0.0785
LOG(COMPOTHERNO(-1))-LOG(COTHERNO(-1))	-0.360375	0.053542	-6.730742	0.0000
GST	0.254086	0.098086	2.590426	0.0108
GST(-1)	-0.002845	0.101371	-0.028067	0.9777
DLOG(COTHERNO)	0.130662	0.076709	1.703351	0.0912
DLOG(COTHERNO(-1))	-0.246437	0.085383	-2.886243	0.0047
DLOG(COMPOTHERNO(-1))	-0.175762	0.078136	-2.249434	0.0264

R-squared	0.365085	Mean dependent var	0.011867
Adjusted R-squared	0.331959	S.D. dependent var	0.118004
S.E. of regression	0.096449	Akaike info criterion	-1.783936
Sum squared resid	1.069781	Schwarz criterion	-1.623050
Log likelihood	115.8201	Hannan-Quinn criter.	-1.718589
F-statistic	11.02108	Durbin-Watson stat	2.133582
Prob(F-statistic)	0.000000		

E8: Detached housing commencements (chain volume)

Dependent Variable: DLOG(CHOUSEVOL)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1988Q1 2018Q2
Included observations: 122

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-0.002494	0.002707	-0.921417	0.3587
LOG(BAHOUSEVOL(-1))-LOG(CHOUSEVOL(-1))	0.849068	0.065621	12.93905	0.0000
DLOG(BAHOUSEVOL)	0.480369	0.044405	10.81785	0.0000
GST(-1)	-0.177607	0.034742	-5.112143	0.0000

R-squared	0.870611	Mean dependent var	0.003876
Adjusted R-squared	0.867322	S.D. dependent var	0.079932
S.E. of regression	0.029115	Akaike info criterion	-4.202883
Sum squared resid	0.100027	Schwarz criterion	-4.110948
Log likelihood	260.3759	Hannan-Quinn criter.	-4.165542
F-statistic	264.6599	Durbin-Watson stat	1.887565
Prob(F-statistic)	0.000000		

E9: Higher-density housing commencements (chain volume)

Dependent Variable: DLOG(COTHERVOL)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1988Q1 2018Q2
Included observations: 122

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.023119	0.010038	2.303231	0.0231
LOG(COTHERVOL(-1))-LOG(BAOTHERVOL(-1))	-0.850425	0.152079	-5.592015	0.0000
DLOG(BAOTHERVOL)	0.521388	0.065561	7.952758	0.0000
DLOG(BAOTHERVOL(-1))	0.045953	0.123995	0.370607	0.7116
DLOG(BAOTHERVOL(-2))	-0.001397	0.090965	-0.015363	0.9878
DLOG(COTHERVOL(-1))	-0.115555	0.126230	-0.915439	0.3619
DLOG(COTHERVOL(-2))	-0.079271	0.085163	-0.930817	0.3539
GST(-1)	0.013992	0.108521	0.128935	0.8976

R-squared	0.584403	Mean dependent var	0.018657
Adjusted R-squared	0.558884	S.D. dependent var	0.157234
S.E. of regression	0.104429	Akaike info criterion	-1.617292
Sum squared resid	1.243219	Schwarz criterion	-1.433422
Log likelihood	106.6548	Hannan-Quinn criter.	-1.542610
F-statistic	22.90064	Durbin-Watson stat	1.990594
Prob(F-statistic)	0.000000		

E10: Alterations and additions commencements (chain volume)

Dependent Variable: DLOG(CAAVOL)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1988Q1 2018Q2
Included observations: 122

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.034945	0.005187	6.736545	0.0000
LOG(CAAVOL(-1))-LOG(BAAAVOL(-1))	-0.691079	0.078361	-8.819172	0.0000
DLOG(BAAAVOL)	0.555305	0.068310	8.129244	0.0000
DLOG(BAAAVOL(-1))	-0.020150	0.067270	-0.299545	0.7651
GST(-1)	-0.261513	0.047196	-5.540980	0.0000

R-squared	0.699772	Mean dependent var	0.002968
Adjusted R-squared	0.689508	S.D. dependent var	0.074833
S.E. of regression	0.041699	Akaike info criterion	-3.476581
Sum squared resid	0.203436	Schwarz criterion	-3.361662
Log likelihood	217.0714	Hannan-Quinn criter.	-3.429904
F-statistic	68.17600	Durbin-Watson stat	2.147701
Prob(F-statistic)	0.000000		

E11: Detached housing commencements (public, chain volume)

Dependent Variable: DLOG(CHOUSEVOL_PUBLIC)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1988Q1 2018Q2
Included observations: 122

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.445465	0.411947	3.508864	0.0006
LOG(CHOUSEVOL_PUBLIC(-1))	-0.300257	0.084934	-3.535183	0.0006
DLOG(CHOUSEVOL_PUBLIC(-1))	-0.273546	0.104267	-2.623514	0.0099
DLOG(CHOUSEVOL_PUBLIC(-2))	-0.003812	0.104279	-0.036556	0.9709
DLOG(CHOUSEVOL_PUBLIC(-3))	0.050814	0.091240	0.556925	0.5786

R-squared	0.264975	Mean dependent var	-0.005281
Adjusted R-squared	0.239846	S.D. dependent var	0.277291
S.E. of regression	0.241762	Akaike info criterion	0.038390
Sum squared resid	6.838492	Schwarz criterion	0.153309
Log likelihood	2.658185	Hannan-Quinn criter.	0.085067
F-statistic	10.54455	Durbin-Watson stat	1.995702
Prob(F-statistic)	0.000000		

E12: Higher-density housing commencements (public, chain volume)

Dependent Variable: DLOG(COTHERVOL_PUBLIC)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample (adjusted): 1988Q3 2018Q2
Included observations: 120 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.137847	0.523628	2.173009	0.0318
LOG(COTHERVOL_PUBLIC(-1))	-0.243867	0.108272	-2.252360	0.0262
DLOG(COTHERVOL_PUBLIC(-1))	-0.486876	0.116198	-4.190062	0.0001
DLOG(COTHERVOL_PUBLIC(-2))	-0.313617	0.113914	-2.753106	0.0069
DLOG(COTHERVOL_PUBLIC(-3))	-0.381888	0.092696	-4.119792	0.0001

R-squared	0.418509	Mean dependent var	-0.026037
Adjusted R-squared	0.398283	S.D. dependent var	0.881506
S.E. of regression	0.683788	Akaike info criterion	2.118435
Sum squared resid	53.77002	Schwarz criterion	2.234580
Log likelihood	-122.1061	Hannan-Quinn criter.	2.165602
F-statistic	20.69185	Durbin-Watson stat	1.630574
Prob(F-statistic)	0.000000		

E13: Alterations and additions commencements (public, chain volume)

Dependent Variable: DLOG(CAAVOL_PUBLIC)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample (adjusted): 1988Q3 2018Q2
Included observations: 120 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.329528	0.203860	1.616447	0.1087
LOG(CAAVOL_PUBLIC(-1))	-0.089483	0.055559	-1.610592	0.1100
DLOG(CAAVOL_PUBLIC(-1))	-0.409814	0.100261	-4.087488	0.0001
DLOG(CAAVOL_PUBLIC(-2))	-0.354218	0.098821	-3.584432	0.0005
DLOG(CAAVOL_PUBLIC(-3))	-0.067145	0.094554	-0.710124	0.4791

R-squared	0.245474	Mean dependent var	0.001079
Adjusted R-squared	0.219230	S.D. dependent var	0.442842
S.E. of regression	0.391301	Akaike info criterion	1.002094
Sum squared resid	17.60839	Schwarz criterion	1.118240
Log likelihood	-55.12565	Hannan-Quinn criter.	1.049261
F-statistic	9.353387	Durbin-Watson stat	2.010975
Prob(F-statistic)	0.000001		

E14: Detached housing work done (chain volume)

Dependent Variable: DLOG(WDHOUSEVOL)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1988Q1 2018Q2
Included observations: 122

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.001749	0.002150	0.813601	0.4176
LOG(WDHOUSEVOL(-1))-LOG(CHOUSEVOL_PRIVATE(-1))	-0.470003	0.047843	-9.823940	0.0000
DLOG(WDHOUSEVOL(-1))	-0.009624	0.045602	-0.211036	0.8332
DLOG(WDHOUSEVOL(-2))	-0.080804	0.035412	-2.281850	0.0243
DLOG(CHOUSEVOL_PRIVATE)	0.423758	0.034183	12.39687	0.0000
GST	0.145296	0.024069	6.036560	0.0000
GST(-1)	-0.139260	0.033024	-4.216923	0.0000

R-squared	0.872137	Mean dependent var	0.005211
Adjusted R-squared	0.865466	S.D. dependent var	0.063272
S.E. of regression	0.023207	Akaike info criterion	-4.633037
Sum squared resid	0.061936	Schwarz criterion	-4.472150
Log likelihood	289.6152	Hannan-Quinn criter.	-4.567690
F-statistic	130.7335	Durbin-Watson stat	2.045568
Prob(F-statistic)	0.000000		

E15: Higher-density housing work done (chain volume)

Dependent Variable: DLOG(WDOTHERVOL)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample (adjusted): 1988Q3 2018Q2
Included observations: 120 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.006704	0.004129	1.623705	0.1072
LOG(WDOTHERVOL(-1))-LOG(COTHERVOL_PRIVATE(-1))	-0.194171	0.053496	-3.629636	0.0004
DLOG(COTHERVOL_PRIVATE)	0.130603	0.027947	4.673220	0.0000
DLOG(COTHERVOL_PRIVATE(-1))	0.037821	0.046647	0.810807	0.4192
DLOG(COTHERVOL_PRIVATE(-2))	0.073610	0.039601	1.858790	0.0657
DLOG(COTHERVOL_PRIVATE(-3))	0.078526	0.032522	2.414587	0.0174
GST	0.164214	0.045213	3.632027	0.0004
GST(-1)	-0.236190	0.045392	-5.203370	0.0000

R-squared	0.621852	Mean dependent var	0.017915
Adjusted R-squared	0.598218	S.D. dependent var	0.067410
S.E. of regression	0.042729	Akaike info criterion	-3.403547
Sum squared resid	0.204484	Schwarz criterion	-3.217714
Log likelihood	212.2128	Hannan-Quinn criter.	-3.328079
F-statistic	26.31148	Durbin-Watson stat	2.008478
Prob(F-statistic)	0.000000		

E16: Alterations and additions work done (chain volume)

Dependent Variable: DLOG(WDAAVOL)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1988Q1 2018Q2
Included observations: 122

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.016480	0.002778	5.932315	0.0000
LOG(WDAAVOL(-1))-LOG(CAAVOL_PRIVATE(-1))	-0.546629	0.056386	-9.694322	0.0000
DLOG(CAAVOL_PRIVATE)	0.370454	0.042306	8.756560	0.0000
GST	0.101486	0.027391	3.705069	0.0003
GST(-1)	-0.244923	0.035605	-6.878841	0.0000

R-squared	0.797175	Mean dependent var	0.003186
Adjusted R-squared	0.790241	S.D. dependent var	0.058981
S.E. of regression	0.027013	Akaike info criterion	-4.344888
Sum squared resid	0.085374	Schwarz criterion	-4.229969
Log likelihood	270.0381	Hannan-Quinn criter.	-4.298211
F-statistic	114.9628	Durbin-Watson stat	2.220353
Prob(F-statistic)	0.000000		

E17: Rental vacancy rate (%)

Dependent Variable: VACANCY/100
Method: Least Squares (Gauss-Newton / Marquardt steps)
Date: 12/21/18 Time: 14:15
Sample: 1983Q1 2018Q2
Included observations: 142
Convergence achieved after 6 iterations
White heteroskedasticity-consistent standard errors & covariance using
outer product of gradients
VACANCY/100 = EXCESS_COMP + C(1)*(VACANCY(-1) - C(2))/100 +
VACANCY(-1)/100 + C(3)*D(UR(-1)/100)

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	-0.151162	0.024864	-6.079593	0.0000
C(2)	2.412196	0.121069	19.92407	0.0000
C(3)	0.206798	0.082588	2.503981	0.0134

R-squared	0.919038	Mean dependent var	0.027989
Adjusted R-squared	0.917873	S.D. dependent var	0.007645
S.E. of regression	0.002191	Akaike info criterion	-9.388018
Sum squared resid	0.000667	Schwarz criterion	-9.325571
Log likelihood	669.5493	Hannan-Quinn criter.	-9.362642
Durbin-Watson stat	1.720493		

E18: CPI rents (real, deflated using trimmed mean CPI)

Dependent Variable: DLOG(RENT_CPI)-INF_3Y
Method: Least Squares (Gauss-Newton / Marquardt steps)
Date: 12/21/18 Time: 14:15
Sample: 1983Q1 2018Q2
Included observations: 142
Convergence achieved after 4 iterations
White heteroskedasticity-consistent standard errors & covariance using outer product of gradients
DLOG(RENT_CPI)-INF_3Y = C(1)/400 + C(2)*(VACANCY(-5) - VACANCY_NATURAL)/100 + C(3)*D(VACANCY(-1)/100) + C(4) *D(VACANCY(-2)/100) + C(5)*D(VACANCY(-3)/100) + C(6) *D(VACANCY(-4)/100) + C(7)*(DLOG(RENT_CPI(-1))-INF_3Y(-1)-C(1) /400) + C(8)*(DLOG(RENT_CPI(-2))-INF_3Y(-2)-C(1)/400) + C(9) *((DLOG(RINC)+DLOG(RINC(-1)))/2-LR_INC) + C(10)*(DLOG(RINC(-2))-LR_INC)

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	0.901008	0.352870	2.553370	0.0118
C(2)	-0.102501	0.040655	-2.521242	0.0129
C(3)	-0.119479	0.097738	-1.222447	0.2237
C(4)	-0.262032	0.121775	-2.151767	0.0332
C(5)	-0.300454	0.097070	-3.095218	0.0024
C(6)	-0.175276	0.097626	-1.795394	0.0749
C(7)	0.529930	0.118757	4.462286	0.0000
C(8)	0.193711	0.107003	1.810343	0.0725
C(9)	0.036692	0.019010	1.930111	0.0557
C(10)	0.048468	0.012212	3.968832	0.0001

R-squared	0.800702	Mean dependent var	0.000355
Adjusted R-squared	0.787114	S.D. dependent var	0.005090
S.E. of regression	0.002349	Akaike info criterion	-9.202105
Sum squared resid	0.000728	Schwarz criterion	-8.993948
Log likelihood	663.3494	Hannan-Quinn criter.	-9.117518
Durbin-Watson stat	2.035132		

E19: Housing prices (real, deflated using trimmed mean CPI)

Dependent Variable: DLOG(RDP*TCPI)-INF_3Y
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1983Q1 2018Q2
Included observations: 142
White heteroskedasticity-consistent standard errors & covariance

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.142670	0.054624	2.611829	0.0100
LOG(RRENT(-1)/RDP(-1))-LOG(UC(-1))	0.022656	0.008718	2.598784	0.0104
DLOG(RDP(-1)*TCPI(-1))-INF_3Y(-1)	0.739314	0.067829	10.89963	0.0000
D(RVMR(-1))	-0.009176	0.002430	-3.776474	0.0002
D(RVMR(-2))	-0.005238	0.001890	-2.771782	0.0064

R-squared	0.692894	Mean dependent var	0.005482
Adjusted R-squared	0.683928	S.D. dependent var	0.020764
S.E. of regression	0.011673	Akaike info criterion	-6.028431
Sum squared resid	0.018669	Schwarz criterion	-5.924352
Log likelihood	433.0186	Hannan-Quinn criter.	-5.986137
F-statistic	77.27517	Durbin-Watson stat	1.596512
Prob(F-statistic)	0.000000	Wald F-statistic	62.04658
Prob(Wald F-statistic)	0.000000		

E20: Adult population (15+ years)

Dependent Variable: DLOG(WAP)
Method: Least Squares
Date: 12/21/18 Time: 14:15
Sample: 1983Q1 2018Q2
Included observations: 142
White heteroskedasticity-consistent standard errors & covariance

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.000287	0.000136	2.106600	0.0369
DLOG(WAP(-1))	0.514310	0.078829	6.524362	0.0000
DLOG(WAP(-2))	0.414611	0.078701	5.268156	0.0000

R-squared	0.809737	Mean dependent var	0.004009
Adjusted R-squared	0.806999	S.D. dependent var	0.000811
S.E. of regression	0.000356	Akaike info criterion	-13.01993
Sum squared resid	1.77E-05	Schwarz criterion	-12.95748
Log likelihood	927.4147	Hannan-Quinn criter.	-12.99455
F-statistic	295.7839	Durbin-Watson stat	1.879626
Prob(F-statistic)	0.000000	Wald F-statistic	367.9006
Prob(Wald F-statistic)	0.000000		

E21: Real household disposable income

Dependent Variable: DLOG(RINC_PER_CAPITA)
Method: Least Squares (Gauss-Newton / Marquardt steps)
Date: 12/21/18 Time: 14:15
Sample (adjusted): 1985Q2 2018Q2
Included observations: 133 after adjustments
White heteroskedasticity-consistent standard errors & covariance
DLOG(RINC_PER_CAPITA) = C(1) + C(2)*DLOG(RINC_PER_CAPITA(-1)) +
C(3)*DLOG(RINC_PER_CAPITA(-2)) + C(4)*DLOG(RINC_PER_CAPIT
A(-3)) + C(5)*DLOG(RINC_PER_CAPITA(-4)) + C(6)*GST(-1) - 0.0016
*((RVMR(-1)-RVMR(-41)))

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	0.003605	0.001225	2.943859	0.0039
C(2)	-0.207404	0.115951	-1.788723	0.0760
C(3)	0.091408	0.096884	0.943483	0.3472
C(4)	0.158653	0.094180	1.684576	0.0945
C(5)	0.049565	0.079508	0.623391	0.5341
C(6)	0.058458	0.002246	26.03123	0.0000

R-squared	0.068745	Mean dependent var	0.002491
Adjusted R-squared	0.032081	S.D. dependent var	0.014902
S.E. of regression	0.014661	Akaike info criterion	-5.563235
Sum squared resid	0.027297	Schwarz criterion	-5.432843
Log likelihood	375.9551	Hannan-Quinn criter.	-5.510249
F-statistic	1.875019	Durbin-Watson stat	1.451208
Prob(F-statistic)	0.103194	Wald F-statistic	573.6565
Prob(Wald F-statistic)	0.000000		

E.2 Identities and Calibrated Equations Used for Simulations

$$cash_t = cash\_exp_t \tag{E22}$$

$$vmr_t = vmr_{t-1} + \Delta\left(cash_t\right) \tag{E23}$$

$$rvmr_t = vmr_t - \left(\left(\frac{tcpi}{tcpi_{t-12}}\right)^{\frac{1}{3}} - 1\right) * 100 \tag{E24}$$

$$i\_10y\_bond_t = \exp\left(\frac{1}{40}\sum_{i=1}^{40}\ln\left(cash\_exp_{t+i}\right)\right) \tag{E25}$$

$$uc_t = rvmr\_exp_t + uc\_running\_cost_t + uc\_transaction\_cost_t + uc\_depreciation_t - uc\_appreciation_t \tag{E26}$$

$$rvmr\_exp_t = \left(1 + \frac{vmr\_exp_t}{100}\right) \Big/ \left(1 + \frac{inf\_exp_t}{100}\right) * 100 - 100 \tag{E27}$$

$$vmr\_exp_t = vmr + \left(i\_10y\_bond_t - cash_t\right) - average\_spread_t \tag{E28}$$

$$inf\_exp_t = 0.9 * inf\_exp_{t-1} + 0.1 * \left(\frac{tcpi_t}{tcpi_{t-4}} - 1\right) * 100 \tag{E29}$$

$$uc\_appreciation_t = uc\_appreciation_{t-1} \tag{E30}$$

$$uc\_depreciation_t = uc\_depreciation_{t-1} \tag{E31}$$

$$uc\_transaction\_cost_t = uc\_transaction\_cost_{t-1} \tag{E32}$$

$$uc\_running\_cost_t = uc\_running\_cost_{t-1} \tag{E33}$$

$$\begin{aligned}\Delta\ln\left(tcpi_t\right) = {} & 0.30 * \Delta\ln\left(tcpi_{t-1}\right) + 0.25 * \Delta\ln\left(tcpi_{t-2}\right) + 0.20 * \Delta\ln\left(tcpi_{t-3}\right) \\ & + 0.15 * \Delta\ln\left(tcpi_{t-4}\right) + 0.1 * 0.025/4\end{aligned} \tag{E34}$$

$$inf\_3y_t = \left(\ln\left(tcpi_t\right) - \ln\left(tcpi_{t-12}\right)\right)/12 \tag{E35}$$

$$rrent_t = rent\_cpi_t / tcpi_t \tag{E36}$$

$$yield_t = rrent_t / rdp_t * yield\_adj * 100 \tag{E37}$$

$$comptotalno_t = comphouseno_t + compotherno_t \tag{E38}$$

$$stock\_no_t = stock\_no_{t-1} + comptotalno_t * \left(1 - demolition\_rate_t\right) \tag{E39}$$

$$stock_t = stock_{t-1} * \left(1 - depreciation\_rate_t\right) + natdi \tag{E40}$$

$$demolition\_rate_t = \frac{1}{20}\sum_{i=1}^{20} demolition\_rate_{t-1} \tag{E41}$$

$$depreciation\_rate_t = \frac{1}{4}\sum_{i=1}^{4} depreciation\_rate_{t-1} \tag{E42}$$

$$\begin{aligned}\Delta\ln\left(bahouseavol_t\right) = {} & \lambda_{house} * \left(\log\left(\frac{bahouseavol_{t-1}}{\left(\frac{rinc_{t-1}}{wap_{t-1}}\right)}\right) - \frac{1}{8}\sum_{i=1}^{8}\log\left(\frac{bahouseavol_{t-i}}{\left(\frac{rinc_{t-i}}{wap_{t-i}}\right)}\right)\right) \\ & + lr\_inc\_per\_wap\end{aligned} \tag{E43}$$

$$bahouseno_t = bahousevol_t / bahouseavol_t * 1000 \tag{E44}$$

$$\Delta \ln\left(baotheravol_t\right) = \lambda_{other} * \left(\log\left(\frac{baotheravol_{t-1}}{\left(\frac{rinc_{t-1}}{wap_{t-1}}\right)} \right) - \frac{1}{8}\sum_{i=1}^{8} \log\left(\frac{baotheravol_{t-i}}{\left(\frac{rinc_{t-i}}{wap_{t-i}}\right)} \right) \right) + lr\_inc\_per\_wap \quad \text{(E45)}$$

$$baotherno_t = baothervol_t / baotheravol_t * 1000 \quad \text{(E46)}$$

$$chousevol\_private_t = chousevol_t - chousevol\_public_t \quad \text{(E47)}$$

$$\Delta \ln\left(nahousevol_t\right) = \Delta \ln\left(wdhousevol_t\right) \quad \text{(E48)}$$

$$cothervol\_private_t = cothervol_t - cothervol\_public_t \quad \text{(E49)}$$

$$\Delta \ln\left(naothervol_t\right) = \Delta \ln\left(wdothervol_t\right) \quad \text{(E50)}$$

$$caavol\_private_t = caavol_t - caavol\_public_t \quad \text{(E51)}$$

$$\Delta \ln\left(naaavol_t\right) = \Delta \ln\left(wdaavol_t\right) \quad \text{(E52)}$$

$$batotalvol_t = baaavol_t + bahousevol_t + baothervol_t \quad \text{(E53)}$$

$$batotalno_t = bahouseno_t + baotherno_t \quad \text{(E54)}$$

$$nanewvol_t = nahousevol_t + naothervol_t \quad \text{(E55)}$$

$$natdi_t = nanewvol_t + naaavol_t \quad \text{(E56)}$$

$$natdival_t = natdi_t * ipd\_natdi_t / 100 \quad \text{(E57)}$$

$$inv\_to\_income_t = natdi_t / rinc_t \quad \text{(E58)}$$

$$rinc_t = rinc\_per\_capita_t * wap_t \quad \text{(E59)}$$

$$ahs_t = \frac{wap_t}{stock\_no_t} * 1000 \quad \text{(E60)}$$

$$excess\_comp_t = \left(\Delta\left(stock\_no_t\right) - \frac{\Delta\left(wap_t\right)}{\left(\frac{1}{20}\sum_{i=1}^{20} ahs_{t-i+1}\right)} \right) \Big/ stock\_no_t \quad \text{(E61)}$$

$$\Delta\left(ur_t\right) = -0.5 * \left(\Delta \ln\left(rinc_t\right) - lr\_inc\right) * 100 \quad \text{(E62)}$$