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Abstract

We demonstrate that the model in Fisher (2007) produces two counterfactual results when the capital tax rate is calibrated to 35%—a rate consistent with estimates of the effective tax rate in the literature. First, household investment lags business investment. Second, household investment is less volatile than business investment with a relative volatility of .62. We show that increasing the degree of household capital complementarity cannot resolve these problems because the model produces counterfactual factor shares in market production relative to the empirical estimates in Fisher (2007). Accounting for U.S. investment dynamics, therefore, remains a significant challenge for macroeconomists.

Key Words: household investment; business investment; capital taxation
JEL Classification: E22, E32

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I Introduction

Fisher (2007) shows that household capital complementarity in market production can explain a key stylized fact of investment dynamics in the US—that household investment leads business investment over the business cycle. Fisher shows that when this complementarity is present in a real business cycle model with home production it makes household capital contribute to producing both home goods and market goods, compared to business capital which contributes to producing only market goods. This asymmetry provides incentives for households to accumulate household capital ahead of business capital after a positive productivity shock. He provides empirical evidence that supports the presence of household capital in market production.

We demonstrate that Fisher's (2007) explanation relies crucially on an extremely high tax of 70% on capital income (nearly two times the statutory corporate tax rate in the US). The model produces two counterfactual results when the capital tax rate is calibrated to 35%—a rate consistent with empirical estimates of the effective capital tax rate in the literature. First, household investment *lags* business investment. Second, household investment is *less* volatile than business investment, with a relative volatility of .62.

Why does the complementarity mechanism fail to generate the lead of household investment over business investment? When capital income taxation is extremely high (70%), the incentive to invest in business capital is heavily dampened relative to the incentive to invest in household capital. However, when capital income taxation is in line with the empirical estimates in the recent literature (35%), the relative incentive to accumulate business capital is sufficiently strengthened and the model cannot generate the lead of household investment over business investment for plausible estimates of the degree of household capital complementarity.

In the rest of this comment, we first discuss why it is correct to use a moderate calibration of 35% for the capital income tax rate instead of 70%. We then demonstrate that Fisher's (2007) model produces counterfactual investment dynamics under the moderate calibration of the capital income tax rate. Finally, we show that increasing the degree of household capital complementarity cannot resolve these problems because the model produces counterfactual factor shares in market production relative to the empirical estimates in Fisher (2007).

We conclude that an explanation of the long-standing stylized facts of US investment dynamics in a plausibly calibrated model remains a significant challenge for understanding the origins of business cycles and their propagation.

II Capital income taxation rate

Following Greenwood, Rogerson, and Wright (1995), several researchers used an extremely high tax on capital income in models with home production (see Panel A in Table 1). The reason is a technical one. Greenwood, Rogerson, and Wright (1995) find that a capital taxation rate of at least 70% is needed for the home-production model to match capital's share coefficient in the market production function in line with National Income Accounts data.[1] But, more recently, Gomme and Rupert (2007) have pointed out that this justification is incorrect because the calculation computes the capital tax rate holding the after-tax real interest rate fixed. Instead, the pre-tax real interest rate should be held fixed and allow after-tax real interest rate to vary with the capital tax rate. With this correction, capital taxation has no effect on matching either the capital share or the capital-output ratio. Gomme and Rupert's (2007) calibration based on the calculation of capital income tax similar to Mendoza, Razin, and Tesar (1994) gives a rate of 29%.

To provide some empirical justification for the extremely high calibration of the capital income tax rate, Greenwood, Rogerson, and Wright (1995) had relied on an earlier paper by Feldstein, Dicks-Mireaux, and Poterba (1983) which computed a high average effective capital tax rate of approximately 65% over 1953-1979 period. Fisher (2007) also cites the Feldstein, Dicks-Mireaux, and Poterba's (1983) estimate for the 70% calibration of marginal capital income tax rate, interpreting it as the effective tax rate. As mentioned above, there is no technical reason to require a high capital tax rate in the model. It is, therefore, appropriate to evaluate model properties using a calibration that closely matches the recent marginal capital income tax rate estimates in the US. Importantly, all of these estimates are significantly lower than the earlier average estimate of Feldstein, Dicks-Mireaux, and Poterba (1983).

[1] In models without home production, this extreme calibration is not necessary as all capital is market capital.

II.I Why is a 35% capital income tax rate the correct calibration?

There are four reasons why a capital income tax rate of 35% is justified as the correct calibration for the US capital income tax rate in the model.

First, this rate is the median of moderate estimates in the literature, i.e. those below 40% (see Table 1, Panel C) and coincides with the calibration of McGrattan and Prescott (2005). McGrattan and Prescott (2005) have pointed out the sharp fall in US corporate income tax rate since the 1960s. They estimate US corporate income tax rate of 43% in the period 1960–1969 and 35% in the period 1990–2001. Notably, their measure of the corporate income tax includes federal, state, and local profits tax accruals as do the estimates of Feldstein, Dicks-Mireaux, and Poterba (1983). Again, these tax rates are significantly lower than the average value of 65% calculated in Feldstein, Dicks-Mireaux, and Poterba (1983) for the pre-1980 period.

Second, the moderate capital tax rate estimates of under 40% in Mendoza, Razin, and Tesar (1994), McGrattan and Prescott (2005), Gomme and Rupert (2007), McDaniel (2007), and Gomme, Ravikumar, and Rupert (2011) (see Panel C in Table 1) are based on a neoclassical framework similar to that in Fisher (2007). These effective tax estimates include corporate taxation, real estate property taxes, state and local taxes, and other taxes (licensing fees) as, for example, in the estimate of Gomme, Ravikumar, and Rupert (2011) for the 1954-2008 period.

Third, the moderate capital tax rates are in line with the very detailed recent work of Cooper et al. (2015) on measuring the tax rate on US business income. To quote Cooper et al. (2015):

> *[...] estimates imply an average tax rate on U.S. business income of 24.3%. We believe this estimate to be the most comprehensive estimate available of the average tax rate on U.S. business income [...]. [H]undreds of economic models require an assumption on the U.S. federal tax rate paid on U.S. business income. Authors frequently use top statutory rates on C-corporate income: 35% (considering only annual corporate taxes) or 45% (considering dividend and capital gains taxation as well). We estimate that this substantially overstates the average tax rate paid on U.S. business income.*

Fourth, as shown in Table 2, the two-quarter lead of household investment over business investment has remained a robust stylized fact. It is present even in the post-1984 US data, a

time period during which the effective tax rate on capital has been below 40%, as noted above. Household investment has also remained more volatile relative to business investment in the post-1984 period. The correct calibration of the capital income tax rate in Fisher's (2007) model to account for these investment dynamics in the post-1984 period is, therefore, 35% and not 70%.

Table 1: **Capital Income Taxation Rates,** τ_k

	(%)
A. Extremely High ($\tau_k \geq 70\%$)	
1. Hornstein and Praschnik (1997)	80
2. Fisher (2007)	70
3. Greenwood, Rogerson, and Wright (1995)	70
4. Gomme, Kydland, and Rupert (2001)	70
B. High (40%< τ_k <70%)	
1. Kydland, Rupert, and Sustek (2016)	61
C. Moderate ($\tau_k \leq$40%)	
1 Gomme, Ravikumar, and Rupert (2011)	40
2. Robert E. Lucas (1990)	36
3. Trabandt and Uhlig (2011)	36
4. McGrattan and Prescott (2005)	**35**
5. Mendoza, Razin, and Tesar (1994)	34
6. McDaniel (2007)	30
7. Gomme and Rupert (2007)	29

III Fisher's (2007) model with a 35% capital income tax rate

Having provided the justification for calibrating the capital income tax rate to 35% in the previous section, we now show that Fisher (2007) model produces counterfactual investment dynamics under this calibration. The appendix describes the complete model with variable names (Table 5), pa-

Table 2: **Dynamic correlations between household investment at $t+j$ and business investment at t: $\rho(x_{ht+j}, x_{mt})$ and the relative volatility of household investment over business investment: $\sigma_{x_h}/\sigma_{x_m}$**

	Correlations					Relative volatility
$j =$	-2	-1	0	1	2	$\sigma_{x_h}/\sigma_{x_m}$
Fisher (2007)	.68	-	.38	-	- .18	1.30
	(.08)		(.07)		(.09)	(.12)
1949Q1-2016Q3	.68	.56	.38	.11	-.13	1.58
	(.05)	(.05)	(.06)	(.07)	(.08)	(.13)
1949Q1-2004Q4	.68	.57	.34	.05	-.21	1.69
	(.06)	(.05)	(.05)	(.06)	(.07)	(.12)
1984Q1-2016Q3	.61	.53	.42	.26	.11	1.15
	(.12)	(.13)	(.13)	(.14)	(.16)	(.15)

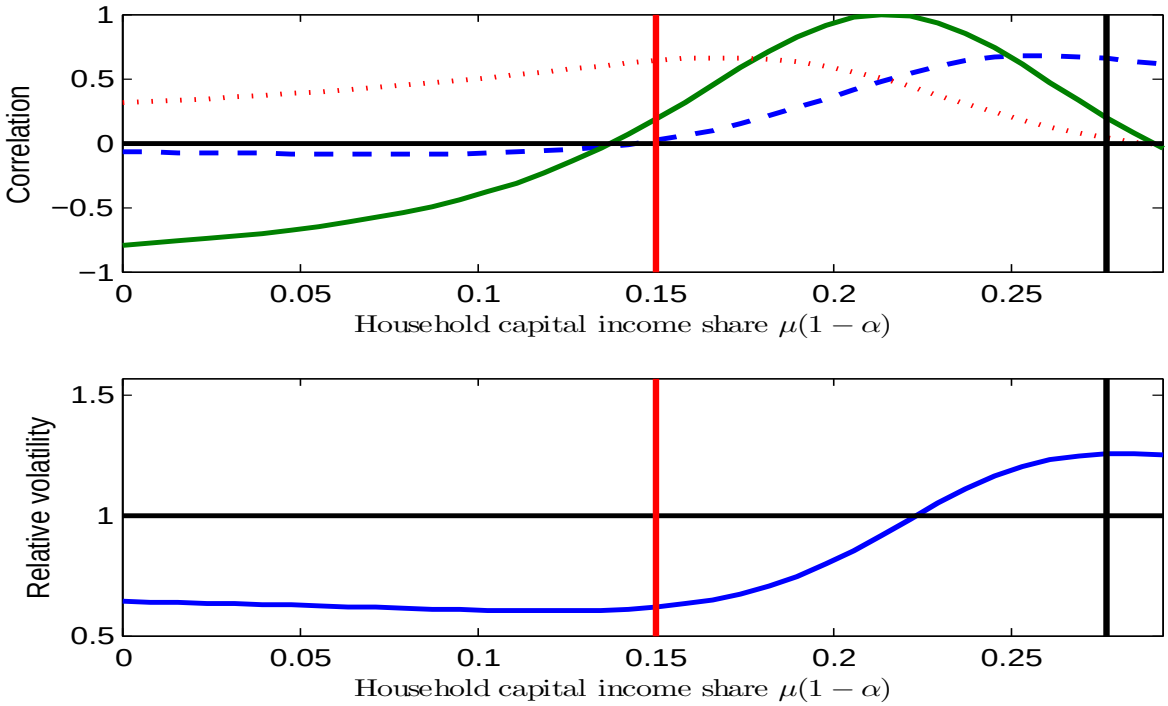
Note—Household investment is residential investment plus consumer durables. Standard errors estimated by Generalized Method of Moments are in parentheses. The source of investment data is the Bureau of Economic Analysis NIPA Table 1. The cyclical components are obtained using the Hodrick-Prescott filter with a smoothing parameter of 1600.

rameters and calibration (Table 6), and factor shares in the production of market goods (Table 7). Throughout, we use exactly the same notation as Fisher's (2007) for convenience. Relative to other models with home production, Fisher introduces a key new parameter μ which controls the degree of household capital complementarity in the market production function: $y_t = k_t^{\alpha}\left[h_{mt}^{\mu}(z_t n_{mt})^{1-\mu}\right]^{1-\alpha}$. The share of household capital, h_{mt}, in the production of non-durable market goods is $\mu(1-\alpha)$.

We now address the main issue of capital income tax calibration. As explained by Fisher (2007), seven parameters $(\psi, \eta, \phi, \delta_h, \alpha, \delta_m, \gamma_z)$ are chosen to match seven calibration targets in the steady-state. On the other hand, the parameter that governs the household capital's share in effective labor, μ, "*is chosen by minimizing a measure of the distance between a given version of the model and*

empirical dynamic correlations between detrended log household and business investment" (Fisher (2007), p.154). Specifically, there are five correlations that enter the loss function, denoted as $\mathcal{L}(\mu)$: the contemporaneous correlation and the cross-correlations between the two investment series that are estimated at one and two quarters leads and lags.[2]

Figure 1: **Dynamic correlations and relative volatilities for** $\tau_k = 0.35$



NOTE—The top panel presents correlations between household investment at $t+j$ with business investment at t for $j = -2$ (*blue dashed line*) , 0 (*solid green line*), 2 (*dotted red line*). Specifically, for regions in that panel where the *dotted red line* is above the two other lines household investment is *lagging* business investment, regions where the *blue dashed line* is above household investment is *leading*, and regions where the *solid green line* is above, no type of investment is leading nor lagging the other type of investment. The vertical red lines show Fisher's (2007) estimate of the household capital income share $\mu(1-\alpha) = .15$ where $\mu = .19$ and $\alpha = .28$. The black vertical lines show the share at the optimized value of $\mu = .35$ and $\mu(1-\alpha) = .28$. The solid blue line in the bottom panel shows the ratio of standard deviations of household investment over business investment.

We use the same calibration targets to simulate the model for seven parameters and consider

[2]See Fisher (2007), equation (13), page 154.

a wide range of values for μ. In Figure 1 is similar to Fisher's (2007) Figure 5 for a 35% capital income tax and display the results for the household capital income share $\mu(1-\alpha)$. In the top panel, we show how correlations are affected by the value of μ. The solid green line corresponds to the contemporaneous correlation between household and business investment, whereas the blue dashed and red dotted lines correspond to the correlations with two-quarter lead and lag, respectively. In the bottom panel, we present the relative volatility of household investment over business investment. There are also two vertical lines in the two panels. The vertical red lines correspond to Fisher's (2007) estimate of $\mu(1-\alpha) = .15$ where $\mu = .19$ and $\alpha = .28$. The black vertical lines correspond to the optimized value of the household capital income share $\mu(1-\alpha) = .28$, where $\mu = .35$ and $\alpha = .21$.

Table 3: **Dynamic correlations between household investment at $t+j$ and business investment at t, $\rho(x_{ht+j}, x_{mt})$, and the relative volatility of household investment over business investment $\sigma_{x_h}/\sigma_{x_m}$. Data and Model**

	Correlations					Relative volatility
$j =$	-2	-1	0	1	2	$\sigma_{x_h}/\sigma_{x_m}$
Data	**.68**	.56	.38	.11	-.13	1.58
	(.05)	(.05)	(.06)	(.07)	(.08)	(.13)
Model ($\mu = .19$)	.02	.12	.19	**.86**	.64	.62
Model ($\mu = .35$)	.66	**.88**	.2	.14	.04	1.26

Note—The dynamic correlations and the relative volatility that appear in the first line are computed from investment series that span from 1949Q1 to 2016Q3 (Table 2), and the other moments reported in the second and third lines are generated by the model for capital income taxation $\tau_k = .35$. The largest correlations are highlighted in bold.

For the same degree of household capital complementarity estimated by Fisher (2007), $\mu = .19$, a 35% capital income tax rate cannot deliver the lead of household investment over business investment. In fact, household investment *lags* business investment as shown in the top panel of Figure 1 and in Table 3. Moreover, the correlation between household investment two quarters

ago and current business investment is essentially zero. However, as shown in Table 2, it is over .5 in the data. In a reverse fashion, the correlation between business investment two quarters ago and current household investment is over .5, whereas it is close to zero in the data. In terms of volatility, household investment is counter-factually *less* volatile than business investment, with a relative volatility of .62 as shown in the bottom panel of Figure 1. Taken together, our analysis reveals that the capital income taxation of 35% in Fisher's (2007) model produces striking changes in investment dynamics relative to a taxation of 70%.

Remarkably, the range of values of $\mu(1-\alpha)$ over which household investment is leading business investment by one quarter, and the contemporaneous correlation between the two types of investment is positive, is both high and narrow. It implies a range of $\mu = [.32, .36]$ for the degree of household capital complementarity. The optimized value of $\mu = .35$ is more than 1.8 times higher than the value of $\mu = .19$ that Fisher (2007, p.155) considers empirically plausible: "*So, [...], $\mu = .19$ seems empirically plausible.*".

Why does the loss function require a much greater complementarity of household capital when the capital taxation is 35%? The reason is that, holding all else equal, the capital tax rate of 35% gives households more incentive to invest in business capital relative to household capital following a positive technology shock. The household capital complementarity channel is, therefore, required to be much stronger (a higher μ) to overcome this incentive that is in favour of business investment. As shown in Figure 1, this is indeed the case. The degree of household capital complementarity must increase to a high level to force the model to deliver the lead of household investment over business investment.

III.I Why is household capital complementarity of $\mu = .35$ an implausible value?

As shown above, when the capital tax rate is 35%, the value of household capital complementarity in the model must increase from $\mu = .19$ to a narrow range of [.32, .36], with the optimized value of $\mu = .35$. But this value is not plausible given the empirical estimates in Fisher's (2007) (Table 1 on page 148). The reason is that when $\mu = .35$, it implies that the share of business capital (.21)

is *less* than the share of household capital in market production (.28).[3] Fisher's (2007) empirical findings, however, show that it is actually the opposite—the estimated business capital share is uniformly and significantly *larger* than the estimated household capital share in market production across all specifications. Table 4 shows Fisher's (2007) empirical estimates.

Table 4: **Household Capital and Business Capital Shares in Market Production (Fisher (2007))**

Household Capital	.16*	.33**	.32**
	(.09)	(.09)	(.09)
Business Capital	.36*	.45**	.45**
	(.03)	(.05)	(.05)

NOTE—The estimates shown are reported in columns 3, 4, & 5 of Table 1 in Fisher (2007) with standard errors in parenthesis. ** significant at the 1% level, * significant at the 10% level.

Note that these shares are quite precisely estimated with very small standard errors. Larger values of μ in the model imply counterfactual relative magnitudes of factor shares when compared to their estimated counterparts shown in Table 4. Specifically, in order to match the seven calibration targets listed in Fisher (2007), the threshold value of μ is .26. At that value the income shares of household and business capital are equal. Any value of μ above that threshold results in a household capital share that is greater than the business capital share, and therefore, not plausible given the estimates in Fisher's (2007) shown in Table 4.

IV Conclusion

We demonstrate that the explanation for the lead of household investment over business investment provided by Fisher (2007) requires an extremely high tax rate of 70% on capital income. When this tax is calibrated to 35% based on the median value of the moderate empirical estimates provided in the literature, the proposed mechanism cannot account for the lead-lag pattern in the US data

[3] Table 7 in the Appendix shows the factor income shares in the production of market goods implied by Fisher's (2007) calibration and our calibration.

for any plausible degree of household capital complementarity. Household investment *lags* business investment, and household investment is *less* volatile relative to business investment. Based on these counterfactual results, we conclude that an explanation of the long-standing stylized facts of US investment dynamics in a plausibly calibrated model remains a significant challenge for understanding the origins of business cycles and their propagation.

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A The Fisher (2007) model

Table 5: Variables in the Fisher (2007) model.

	Model variables
1. c_{mt}	Consumption good purchased from the market
2. c_{ht}	Consumption good produced at home
3. n_{ht}	Hours used in home production
4. n_{mt}	Hours supplied to the labour market
5. $\tilde{n}_{mt}$	Effective hours supplied to the market
6. h_{nt}	Stock of household capital used in producing c_{ht}
7. h_{ct}	Stock of household capital used in producing $\tilde{n}_{mt}$
8. z_t	Neutral technology shock
9. p_{mt}	Price of household's investment in business capital
10. x_{mt}	Quantity of household's investment in business capital
11. p_{ht}	Price of household's investment in household capital
12. x_{ht}	Quantity of household's investment in household capital
13. k_t	Household's stock of business capital
14. h_t	Household's stock of household capital
15. w_t	Wage for effective hours
16. r_t	Rental on capital
17. h_t	Total household capital
18. v_{mt}	Business investment-specific technology
19. v_{ht}	Household investment-specific technology
20. θ_t	Exogenous technology shock
21. ξ_t	Government revenues
22. y_t	Market output

Table 6: Parameters in the Fisher (2007) model: $\tau_k = 0.7$ and the optimized value of household capital complementarity $\hat{\mu} = 0.19$. For our calibration of $\tau_k = 0.35$, the optimal value of $\hat{\mu} = 0.35$.

Model parameters and calibration			
	Fisher (2007)	Our calibration	
1. τ_k	.7	.35	Tax rate on capital income
2. μ	.19	.35	Optimal household capital's share in effective labour
3. ψ	.56	.42	Weight parameter on consumption of home-produced good
4. η	.76	.67	Weight parameter on leisure
5. ϕ	.19	.05	Share of household capital in producing c_{ht}
6. δ_h	.017	.019	Depreciation rate on household capital
7. α	.28	.21	Share of business capital in market production
8. δ_m	.019	.019	Depreciation rate on market capital
9. γ_z	1.0026	1.001	Rate of neutral technical change
10. τ_n	.25	.25	Tax rate on labour income
11. β	.99	.99	Discount factor
12. γ_m	1.002	1.002	Rate of household-specific technical change
13. γ_h	1.003	1.003	Rate of business-specific technical change
14. ρ	.95	.95	Persistence of neutral technology shock
15. σ	.007	.007	Volatility of the neutral technology shock

NOTE—Following Fisher (2007), parameters $\psi, \eta, \phi, \delta_h, \alpha, \delta_m$, and γ_z are chosen to match seven calibration targets in the steady-state.

Table 7: A different household capital share μ also implies different factor income shares.

Factor income shares in the production of market goods		
	Fisher (2007)	Our calibration
Household capital h_{mt}	.14	.28
Business capital k_t	.28	.21
Hours worked n_t	.58	.51

A.I Households

The representative household's utility maximization problem is

$$\begin{aligned}\mathcal{L} \quad = \quad & E_0 \sum_{t=0}^{\infty} \ln c_{mt} + \psi \ln \left(h_{ct}^{\phi} \left(z_t n_{ht} \right)^{1-\phi} \right) + \eta \ln \left(1 - n_{mt} - n_{ht} \right) + \\ & \lambda_{1t} \left[(1-\tau_k) r_t k_t + (1-\tau_n) w_t h_{nt}^{\mu} \left(z_t n_{mt} \right)^{1-\mu} + \delta_m \tau_k k_t + \xi_t - c_{mt} - p_{mt} \left(k_{t+1} - (1-\delta_m) k_t \right) - p_{ht} \left(h_{t+1} - (1-\delta_h) h_t \right) \right] + \\ & \lambda_{2t} \left[h_t - h_{nt} - h_{ct} \right] \end{aligned} \tag{1}$$

First-order conditions

c_mt:

$$\frac{1}{c_{mt}} = \lambda_{1t} \tag{2}$$

h_ct:

$$\frac{\psi}{h_{ct}^{\phi} (z_t n_{ht})^{1-\phi}} (z_t n_{ht})^{1-\phi} h_{ct}^{\phi-1} = \lambda_{1t} \tag{3}$$

$$\frac{\psi \phi}{h_{ct}} = \lambda_{2t} \tag{4}$$

n_ht:

$$\frac{\psi (1-\phi)}{n_{ht}} = \frac{\eta}{1 - n_{mt} - n_{ht}} \tag{5}$$

n_mt

$$\lambda_{1t} (1-\tau_n)(1-\mu) w_t h_{nt}^{\mu} n_{mt}^{-\mu} z_t^{1-\mu} = \frac{\eta}{1 - n_{mt} - n_{ht}} \tag{6}$$

k_t+1

$$p_{mt} = \beta E_t \frac{\lambda_{1t+1}}{\lambda_{1t}} \left(p_{mt+1} (1-\delta_m) + (r_{t+1} - (1-\delta_m) \tau_k) \right) \tag{7}$$

h_nt

$$\frac{\lambda_{2t}}{\lambda_{1t}} = (1-\tau_n) \mu w_t (z_t n_{mt})^{1-\mu} h_{nt}^{\mu-1} \tag{8}$$

h_t+1

$$p_{ht} = \beta E_t \frac{\lambda_{1t+1}}{\lambda_{1t}} \Big(p_{ht+1}(1 - \delta_h - \tau_h) + \frac{\lambda_{2t+1}}{\lambda_{1t+1}} \Big) \tag{9}$$

Household-level production functions

$$\tilde{n}_{mt} = h_{nt}^{\mu} (z_t n_{mt})^{1-\mu} \tag{10}$$

$$c_{ht} = h_{ct}^{\phi} (z_t n_{ht})^{1-\phi} \tag{11}$$

Investment equations[4]

$$x_{mt} = k_{t+1} - (1 - \delta_m) k_t \tag{12}$$

$$x_{ht} = h_{t+1} - (1 - \delta_h) h_t \tag{13}$$

A.II Firms

The representative firm's profit-maximization problem is

$$\max_{\tilde{n}_{mt}, k_t} k_t^{\alpha} \tilde{n}_{mt}^{1-\alpha} - r_t k_t - w_t \tilde{n}_{mt} \tag{14}$$

The FOCs with respect to **k_t** and $\tilde{\mathbf{n}}_{\mathbf{mt}}$ are:

$$\alpha k_t^{\alpha-1} = r_t \tag{15}$$

$$(1 - \alpha) \tilde{n}_{mt}^{-\alpha} = w_t \tag{16}$$

[4] We consider one-period time-to-build as Fisher (2007) shows that increasing time-to-build *per se* does not reconcile real business cycle theory with the investment dynamics.

A.III Market clearing and investment prices

Expressions for output from the aggregate supply and demand sides:

$$y_t = k_t^{\alpha} \tilde{n}_{mt}^{1-\alpha} \tag{17}$$

$$y_t = c_{mt} + p_{mt} x_{mt} + p_{ht} x_{ht} \tag{18}$$

Exogenously evolving investment prices:

$$p_{mt} = \frac{1}{v_{mt}} \tag{19}$$

$$p_{ht} = \frac{1}{v_{ht}} \tag{20}$$

A.IV Government

$$\xi_t = \tau_k r_t k_t + \tau_n w_t \tilde{n}_{mt} - \delta_m \tau_k k_t \tag{21}$$

B Stationarized model

Since business and household investment-specific technology grow at constant rates, we need to stationarize the model presented in the previous section. First, we define $v_{zt} = \gamma_z^t$ which specifies the deterministic growth component. All hatted variables correspond to stationary variables. $\hat{y}_t = \frac{y_t}{A_{t-1}}$, $\hat{k}_{t-1} = \frac{k_{t-1}}{A_{t-1} v_{kt-1}}$, $\hat{h}_{t-1} = \frac{h_{t-1}}{A_{t-1} v_{ht-1}}$, $\hat{h}_{ct-1} = \frac{h_{ct-1}}{A_{t-1} v_{ht-1}}$, $\hat{h}_{nt-1} = \frac{h_{nt-1}}{A_{t-1} v_{ht-1}}$ where $A_t = v_{zt} \left[v_{ht}^{\mu(1-\alpha)} v_{kt}^{\alpha} \right]^{1/((1-\mu)(1-\alpha))}$.

The expression for output for which *effective* labor supply has been substituted in is as follows:

$$\hat{y}_t = \hat{k}_{t-1}^{\alpha} \hat{h}_{nt-1}^{\mu(1-\alpha)} \left(\gamma_z z_t n_{mt} \right)^{(1-\mu)(1-\alpha)} \tag{22}$$

As for the expenditure side, $\hat{x}_{mt} = \frac{x_{mt}}{A_{t-1} v_{kt-1}}$, $\hat{x}_{ht} = \frac{x_{ht}}{A_{t-1} v_{ht-1}}$ and $\hat{c}_{mt} = \frac{c_{mt}}{A_{t-1}}$, so that:

$$\hat{y}_t = \hat{c}_{mt} + \hat{x}_{mt} + \hat{x}_{ht} \tag{23}$$

The capital accumulation equations are as follows:

$$\hat{x}_{mt} = \gamma_A \gamma_k \hat{k}_t - (1-\delta_m)\hat{k}_{t-1} \tag{24}$$

$$\hat{x}_{ht} = \gamma_A \gamma_h \hat{h}_t - (1-\delta_h)\hat{h}_{t-1} \tag{25}$$

where $\gamma_A = \gamma_z \left(\gamma_m^{\alpha}\gamma_h^{\mu(1-\alpha)}\right)^{1/((1-\mu)(1-\alpha))}$. As for the firms' FOCs:

$$\alpha \hat{y}_t = \hat{r}_t \hat{k}_{t-1} \tag{26}$$

$$(1-\alpha)\hat{y}_t = \widehat{w_t \tilde{n}_{mt}} \tag{27}$$

where $\hat{r}_t = r_t v_{kt-1}$ and $\widehat{w_t \tilde{n}_{mt}} = \dfrac{w_t \tilde{n}_{mt}}{A_{t-1}}$.

As for the remaining FOCs, they are obtained by substituting in λ_{1t} and λ_{2t} and using the definitions of the hatted variables.

$$\frac{\eta}{1-n_{mt}-n_{ht}} = \frac{(1-\tau_n)(1-\mu)\widehat{w_t \tilde{n}_{mt}}}{\hat{c}_{mt} n_{mt}} \tag{28}$$

$$\frac{\eta}{1-n_{mt}-n_{ht}} = \frac{\psi(1-\phi)}{n_{ht}} \tag{29}$$

$$\frac{\gamma_A}{\hat{c}_{mt}} = \frac{\beta}{\hat{c}_{mt+1}}\left((1-\delta_m(1-\tau_m))/\gamma_m + (1-\tau_m)\hat{r}_{t+1}\right) \tag{30}$$

$$\frac{\gamma_A}{\hat{c}_{mt}} = \frac{\beta(1-\delta_h-\tau_h)}{\gamma_h \hat{c}_{mt+1}} + \frac{\beta\psi\phi}{\hat{h}_{ct}} \tag{31}$$

$$\frac{\gamma_A}{\hat{c}_{mt}} = \frac{\beta}{\hat{c}_{mt+1}}\left((1-\delta_h-\tau_h)/\gamma_h + \frac{(1-\tau_n)\mu \widehat{w_{t+1}\tilde{n}_{mt+1}}}{\hat{h}_{mt}}\right) \tag{32}$$