Online Appendix for "Climate Policy, Financial Frictions, and Transition Risk"

A Details on banks' optimization problem

We formulate the banker's optimization problem in recursive form. First, using the flow of funds constraint (5) to replace deposits $D_{j,t}$, we can express the evolution of bank's net worth (6) as

$$N_{j,t+1} = \left[R^b_{k,t+1} - \left(1+\tau^b_t\right) R_t\right] Q^b_t S^b_{j,t} + \left[R^g_{k,t+1} - \left(1+\tau^g_t\right) R_t\right] Q^g_t S^g_{j,t} + R_t N_{j,t}. \tag{A1}$$

The banker's optimization problem in recursive form then becomes:

$$V_{j,t} = \max_{S^b_{j,t}, S^g_{j,t}} \mathbb{E}_t \left\{\left[\left(1-\gamma\right) M_{t,t+1} N_{j,t+1} + \gamma M_{t,t+1} V_{j,t+1}\right]\right\}, \tag{A2}$$

subject to the incentive constraint (7) and the evolution of net worth (A1).

We guess and later verify that the value function is linear in net worth $N_{j,t}$,

$$V_{j,t} = \varphi_t N_{j,t}, \tag{A3}$$

where φ_t is the time-varying coefficient common across banks. It is convenient to define the variables:

$$\chi^b_t \equiv \mathbb{E}_t \left[\Omega_{t+1}\left(R^b_{k,t+1} - \left(1+\tau^b_t\right) R_t\right)\right], \tag{A4}$$

$$\chi^g_t \equiv \mathbb{E}_t \left\{\Omega_{t+1}\left[R^g_{k,t+1} - \left(1+\tau^g_t\right) R_t\right]\right\}, \tag{A5}$$

$$\nu_t \equiv \mathbb{E}_t \left[\Omega_{t+1} R_t\right], \tag{A6}$$

where $\Omega_{t+1} \equiv M_{t,t+1}\left(1-\gamma+\gamma\varphi_{t+1}\right)$ can be interpreted as the banker's effective stochastic discount factor; χ^b_t and χ^g_t are the expected discounted (tax adjusted) excess returns on brown and green assets, respectively, relative to deposits, and ν_t is the expected discounted cost of raising an additional unit of deposits.

Using the definitions (A4) −(A6), the conjecture (A3), and (A1), we can rewrite the Bellman equation (A2) as

$$V_{j,t} = \max_{S^b_{j,t}, S^g_{j,t}} \left\{\chi^b_t Q^b_t S^b_{j,t} + \chi^g_t Q^g_t S^g_{j,t} + \nu_t N_{j,t}\right\}. \tag{A7}$$

The incentive constraint (7) then becomes,

$$\chi_t^b Q_t^b S_{j,t}^b + \chi_t^g Q_t^g S_{j,t}^g + \nu_t N_{j,t} \geq \kappa \left(Q_t^b S_{j,t}^b + Q_t^g S_{j,t}^g \right). \tag{A8}$$

The Lagrangian function for this problem is

$$\pounds_t = \left(\chi_t^b Q_t^b S_{j,t}^b + \chi_t^g Q_t^g S_{j,t}^g + \nu_t N_{j,t} \right) (1 + \lambda_t) - \lambda_t \kappa \left(Q_t^b S_{j,t}^b + Q_t^g S_{j,t}^g \right), \tag{A9}$$

where λ_t is the Lagrange multiplier on the incentive constraint (A8). The first order optimality conditions are:

$$(1 + \lambda_t) \chi_t^b = \lambda_t \kappa, \tag{A10}$$

$$(1 + \lambda_t) \chi_t^g = \lambda_t \kappa, \tag{A11}$$

$$\lambda_t \left[\chi_t^b Q_t^b S_{j,t}^b + \chi_t^g Q_t^g S_{j,t}^g + \nu_t N_{j,t} - \kappa \left(Q_t^b S_{j,t}^b + Q_t^g S_{j,t}^g \right) \right] = 0, \text{ with } \lambda_t \geq 0. \tag{A12}$$

Combining the FOCs (A10) and (A11) yields $\chi_t^b = \chi_t^g$, which gives equation (12) in the main text,

$$\mathbb{E}_t \left\{ \Omega_{t+1} \left[R_{k,t+1}^b - \left(1 + \tau_t^b\right) R_t \right] \right\} = \mathbb{E}_t \left\{ \Omega_{t+1} \left[R_{k,t+1}^g - \left(1 + \tau_t^g\right) R_t \right] \right\}. \tag{A13}$$

From (A10) we also have $\lambda_t = \frac{\chi_t^b}{\kappa - \chi_t^b}$. The incentive constraint (A8) binds whenever the Lagrange multiplier $\lambda_t > 0$, or when $0 < \chi_t^b < \kappa$. In our realistic parametrization of the model, the incentive constraint always binds in a local region of the steady state. When the incentive constraint binds, the amount of bank's assets is limited by bank's equity capital,

$$Q_t^b S_{j,t}^b + Q_t^g S_{j,t}^g = \frac{\nu_t}{\kappa - \chi_t^b} N_{j,t}. \tag{A14}$$

Using (A14) and the optimality conditions we can verify our conjecture (A3):

$$V_{j,t} = \varphi_t N_{j,t} = \chi_t^b \frac{\nu_t}{\kappa - \chi_t^b} N_{j,t} + \nu_t N_{j,t} = \frac{\kappa \nu_t}{\kappa - \chi_t^b} N_{j,t}, \tag{A15}$$

$$\Rightarrow \varphi_t = \frac{\kappa \nu_t}{\kappa - \chi_t^b}. \tag{A16}$$

Since χ_t^b, χ_t^g and ν_t only depend on aggregate variables, φ_t is not individual bank-specific either. Aggregating (A14) across banks, and after imposing (A16), gives equation (11) in the main text.

B Full set of equilibrium conditions

$$L_t = \left[\left(L_t^b \right)^{1+\rho_L} + \left(L_t^g \right)^{1+\rho_L} \right]^{\frac{1}{1+\rho_L}}, \tag{B1}$$

$$M_{t,t+1} = \beta \frac{\left(C_{t+1} - \varpi \frac{L_{t+1}^{1+\xi}}{1+\xi} \right)^{-\eta}}{\left(C_t - \varpi \frac{L_t^{1+\xi}}{1+\xi} \right)^{-\eta}}, \tag{B2}$$

$$1 = \mathbb{E}_t \left(M_{t,t+1} R_t \right), \tag{B3}$$

$$w_t^i = \varpi L_t^{\xi-\rho_L} \left(L_t^i \right)^{\rho_L}, \quad \text{for } i = \{g, b\}, \tag{B4}$$

$$\chi_t^b = \mathbb{E}_t \left[\Omega_{t+1} \left(R_{k,t+1}^b - \left(1 + \tau_t^b \right) R_t \right) \right], \tag{B5}$$

$$\chi_t^g = \mathbb{E}_t \left[\Omega_{t+1} \left(R_{k,t+1}^g - \left(1 + \tau_t^g \right) R_t \right) \right], \tag{B6}$$

$$\nu_t = \mathbb{E}_t \left[\Omega_{t+1} R_t \right], \tag{B7}$$

$$\Omega_{t+1} = M_{t,t+1} \left(1 - \gamma + \gamma \varphi_{t+1} \right), \tag{B8}$$

$$\chi_t^b = \chi_t^g, \tag{B9}$$

$$\varphi_t = \frac{\kappa \nu_t}{\kappa - \chi_t^b}, \tag{B10}$$

$$Q_t^b S_t^b + Q_t^g S_t^g = \frac{\nu_t}{\kappa - \chi_t^b} N_t, \tag{B11}$$

$$N_{t+1} = \gamma \left[\sum_{i=\{g,b\}} R_{k,t+1}^i Q_t^i S_t^i - R_t D_t \right] + \zeta \sum_{i=\{g,b\}} Q_t^i S_t^i, \tag{B12}$$

$$D_t = (1 + \tau_t^b) Q_t^b S_t^b + (1 + \tau_t^g) Q_t^g S_t^g - N_t, \tag{B13}$$

$$Y_t = \left[\left(\pi^b \right)^{\frac{1}{\rho_Y}} \left(Y_t^b \right)^{\frac{\rho_Y - 1}{\rho_Y}} + \left(1 - \pi^b \right)^{\frac{1}{\rho_Y}} \left(Y_t^g \right)^{\frac{\rho_Y - 1}{\rho_Y}} \right]^{\frac{\rho_Y}{\rho_Y - 1}}, \tag{B14}$$

$$Y_t^i = \left[1 - d \left(X_t \right) \right] A_t \left(K_{t-1}^i \right)^{\alpha^i} \left(L_t^i \right)^{1-\alpha^i}, \text{ for } i = \{g, b\}, \tag{B15}$$

$$p_t^b = \left(\frac{\pi^b Y_t}{Y_t^b} \right)^{\frac{1}{\rho_Y}}, \tag{B16}$$

$$p_t^g = \left(\frac{\left(1 - \pi^b \right) Y_t}{Y_t^g} \right)^{\frac{1}{\rho_Y}}, \tag{B17}$$

$$X_t = \delta_X X_{t-1} + e_t + e_t^{\text{row}}, \tag{B18}$$

$$e_t = (1-\mu_t)\, Y_t^b, \tag{B19}$$

$$Z_t = \theta_1 \mu_t^{\theta_2} Y_t^b, \tag{B20}$$

$$w_t^b = \left(1-\alpha^b\right) \frac{Y_t^b}{L_t^b} \left[p_t^b - \theta_1 \mu_t^{\theta_2} - \tau_t^e (1-\mu_t)\right], \tag{B21}$$

$$\tau_t^e = \theta_1 \theta_2 \mu_t^{\theta_2 - 1}, \tag{B22}$$

$$R_{k,t}^b = \frac{\alpha^b \frac{Y_t^b}{K_{t-1}^b} \left[p_t^b - \theta_1 \mu_t^{\theta_2} - \tau_t^e (1-\mu_t)\right] + \left(1-\delta^b\right) Q_t^b}{Q_{t-1}^b}, \tag{B23}$$

$$w_t^g = (1-\alpha^g) \frac{p_t^g Y_t^g}{L_t^g}, \tag{B24}$$

$$R_{k,t}^g = \frac{\alpha^g \frac{p_t^g Y_t^g}{K_{t-1}^g} + (1-\delta^g)\, Q_t^g}{Q_{t-1}^g}, \tag{B25}$$

$$\begin{aligned} Q_t^i = {} & 1 + \frac{\phi^i}{2}\left(\frac{I_t^i}{I_{t-1}^i} - 1\right)^2 + \phi^i \left(\frac{I_t^i}{I_{t-1}^i} - 1\right) \frac{I_t^i}{I_{t-1}^i} + \\ & - \mathbb{E}_t \left\{ M_{t,t+1} \phi^i \left(\frac{I_{t+1}^i}{I_t^i} - 1\right) \left(\frac{I_{t+1}^i}{I_t^i}\right)^2 \right\}, \text{for } i = \{g, b\}, \end{aligned} \tag{B26}$$

$$K_t^i = \left(1-\delta^i\right) K_{t-1}^i + I_t^i, \ \text{for } i = \{g, b\}, \tag{B27}$$

$$Q_t^i S_t^i = Q_t^i K_t^i, \quad \text{for } i = \{g, b\}, \tag{B28}$$

$$Y_t = C_t + \sum_{i=\{g,b\}} I_t^i + Z_t + \sum_{i=\{g,b\}} \frac{\phi^i}{2} \left(\frac{I_t^i}{I_{t-1}^i} - 1\right)^2 I_t^i. \tag{B29}$$

Given government policies $(\tau_t^e, \tau_t^b, \tau_t^g)$ and exogenous total factor productivity (A_t), a competitive equilibrium is described by the stochastic sequences of endogenous variables $\mathbf{J}_t \equiv \left[\left\{L_t^i, K_t^i, I_t^i, Y_t^i, S_t^i, w_t^i, R_{k,t}^i, Q_t^i, p_t^i\right\}_{i=g,b}, C_t, M_{t,t+1}, L_t, Y_t, Z_t, \mu_t, e_t, X_t, N_t, D_t, R_t, \chi_t^b, \chi_t^g, \nu_t, \varphi_t, \Omega_{t+1}\right]$ that satisfy the system of equations B1-B29.

C The Ramsey-efficient policy problem

For a given set of available instruments (e.g., only τ_t^e; only $\tau_t^b = \tau_t^g$; τ_t^b and τ_t^g; τ_t^e and $\tau_t^b = \tau_t^g$) the Ramsey planner solves:

$$\max_{\{\mathbf{J}_t,\text{ and a given set of instruments}\}_{t=0}^{\infty}} \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\eta} \left(C_t - \varpi \frac{\left[\left(L_t^b\right)^{1+\rho_L} + \left(L_t^g\right)^{1+\rho_L} \right]^{\frac{1+\xi}{1+\rho_L}}}{1+\xi} \right)^{1-\eta} \right\}, \tag{C1}$$

subject to the constraints of the competitive equilibrium (i.e., equations B1-B29). As is common in the literature, we take the 'timeless perspective' approach to implement the solution to the Ramsey problem; the policymaker is able to commit to a state-contingent dynamic policy announced in time 0. We implement the solution in Dynare.

D Transition risk: Sensitivity analysis

In this section, we present more simulations extending the simulations exploring transition risk from Section 4, though we vary the assumptions about the timing of the policies and parameter values.

Figure A3 contrasts the abrupt implementation of an exogenous carbon tax to a gradual, ramp-up approach, which is typically recommended by IAMs like DICE. A surprise carbon tax is introduced in period 5. Under the gradual simulation, the tax rate starts low and increases linearly to the efficient level (17.2 dollars per ton) by period 25 and permanently stays at that efficient level thereafter. The experiment illustrates that gradual "ramp-up" causes a milder recession and avoids the sudden drop in output caused by the abrupt tax increase. The decrease in green capital is much less severe under the gradual tax, and the level of green capital rises above the original steady-state level much more quickly.

In the next simulation, presented in Figure A4, we consider how the preannouncement of a carbon tax, rather than its sudden implementation, affects the results. In these simulations, the carbon tax of 17.2 dollars per ton is announced in period 5 (unexpectedly), but it does not take effect until period 10. Because asset prices are forward looking, the negative effects of the announcement on asset prices, banks' net worth, and investment are immediate, albeit milder than in the baseline scenario. The recession is milder with the pre-announcement, and green production and capital also fall by less.

Both of the previous sets of simulations explore how the timing of the carbon tax can affect the transition and possibly alleviate the threat of a recession. Of course, the timing of climate policy is often constrained by political economy elements, so a gradual implementation might be an inferior solution to implementing macroprudential policy, which allows for abrupt implementations as well. Climate damages are also higher with gradual implementation, in terms of eventual temperature increase.

In the next set of simulations that we explore here, we instead investigate the timing of the macroprudential policies. In the results presented in the main text and presented in Figure 2, the macroprudential policy is in place before the carbon tax is enacted, and the initial steady state of the simulations with the macroprudential policy is the steady state that includes that policy. In Figure A5 we instead introduce the macroprudential policies at the same time as the introduction of the carbon tax (period 5). In these simulations, the magnitudes of the macroprudential policies are identical to those in Figure 2, though the timing differs.

Figure A5 demonstrates that the macroprudential policies are still quite effective at ameliorating the impact of the recession – aggregate investment falls by less and rebounds much more quickly, and aggregate output does not fall as much.

We consider the case where macroprudential policy is introduced first and then, after some time, but before the new steady state is reached, the climate policy shock hits the economy. Figure A6 shows the transition dynamics in response to an unexpected introduction of permanent macroprudential policies in period 2 and then the permanent emissions tax in period 11. The figure illustrates that macroprudential policy pushes bank equity up, resulting in higher aggregate investment spending. Aggregate output also expands slightly before the emissions tax is introduced. At the time of the introduction of climate policy, the share of brown capital in the economy is about 36% and, therefore, banks' balance sheets are less exposed to the carbon tax shock relative to the case with no macroprudential policy. As a result, bank equity capital falls by less in response to the emissions tax shock. With macroprudential policy in place, aggregate investment and output fall by less. In addition, macroprudential policy helps green capital expand from the very beginning of the transition.

The next set of simulations considers the case when emissions tax shock follows an AR(1) stochastic process as described in Figure A7. The previous simulations assumed perfect foresight after the tax policy is introduced. Figure A7 shows the results of the stochastic simulations when agents in the economy are repeatedly surprised by carbon tax shocks in periods 5, 15, and 25. Qualitatively, the results are very similar to the experiments with the one time, unexpected introduction of a permanent carbon tax. Macroprudential policies are again effective at mitigating the transition risks.

We next present results under an alternate calibration in which we calibrate our pollution values based on the current real-world carbon stock, rather than the carbon stock taken from a long-run average under a run of DICE. As described in the text, our initial calibration was done to ensure a high enough carbon tax would result, given that the relatively high carbon tax in DICE arises from TFP growth, which is absent in our model. In this alternative calibration presented here, the steady-state pollution stock corresponds to 851 GtC. With the recalibration under this assumption, the first-best steady-state carbon tax is now just about 10 dollars per ton of CO_2. Figure A8 shows that the results are qualitatively very similar to baseline calibration, but the smaller carbon tax shock implies smaller transition effects. Note that even when we start the simulation in the low-pollution-stock steady state, if we hit the model with the carbon tax of the same size as in our baseline calibration, the results are also quantitatively almost the same as in the baseline.

Figure A9 further explores the sensitivity of the transition dynamics in the model with financial frictions (solid lines in Figure 1) to parameter values. Specifically, we vary two parameters that are relevant in the transition to a low carbon economy: (i) the elasticity of substitution parameter between brown and green inputs, ρ_Y, and the abatement cost parameter, θ_1. In the baseline calibration these parameters are set to $\rho_Y = 2$ and $\theta_1 = 0.0334$. In the sensitivity exercises we consider a lower degree of substitutability, $\rho_Y = 1.2$, and higher abatement cost, $\theta_1 = 0.15$. We vary these parameters one at a time comparing the results with the baseline calibration under the same carbon tax shock. Figure A9 shows that under the alternative parameter values, the results are qualitatively very similar to the baseline case. Note that these sensitivity results are monotonic in the parameters' values.

Quantitatively, with the lower substitutability between brown and green inputs (dashed lines), aggregate output and investment fall by less, largely because of the smaller decline in brown production in response to the introduction of the carbon tax. However, with the low elasticity of substitution, the green sector experiences a more severe and prolonged recession as it is harder for the economy to move away from brown production. The responses of banks' net worth and credit spreads are not very different from the baseline case. When abatement cost is high (dotted lines), emissions do not fall nearly as much as in the baseline and the economy experiences a more severe recession throughout the transition. Since it is too costly to abate, brown firms scale down their production leading to lower overall economic activity. The effects of the carbon tax shock on banks' net worth and credit supply are again similar to the baseline calibration.

E Steady-state Ramsey-efficient policies: Sensitivity analysis

Here we present the results from sensitivity analyses varying two parameters that control the degree of distortions due to financial frictions. Figure A10 shows how the second-best steady-state carbon tax varies when we exogenously change the parameters ζ (Panel (a)) and κ (Panel (b)). We vary banks' transfer parameter ζ from its baseline value to higher values and the agency problem parameter κ from its baseline to lower values. The parameter ζ is the banks' transfer parameter; a higher ζ means that exogenous transfers from households to banks increase, which directly increases banks' net worth. Banks can thus intermediate more capital to the economy. The base case calibrated value of ζ is 0.0029. As we increase this parameter, it reduces the steady-state distortion in allocations coming from the financial frictions. When ζ is about 0.00846, the second-best emissions tax is the same as the first-best tax ($17.2 per ton), meaning that the inefficiencies from the financial friction in the steady state have been eliminated.

The parameter κ is the agency problem parameter; a lower κ means that incentives to divert funds for banks are lower, so depositors are willing to lend more to the banks. As a result, banks can extend more credit to the economy. The base case calibrated value of κ is 0.3313. As we reduce this parameter, it reduces the distortion from financial frictions. Again, there is a low enough value for κ (about 0.1135) for which the second-best emissions tax is the same as first-best tax.

Table A2 further explores the sensitivity of the steady state results with respect to other selected technology and climate parameters. Specifically, we consider (i) lower value of substitutability parameter ($\rho_Y = 1.2$) between green and brown goods, (ii) higher value of abatement cost parameter ($\theta_1 = 0.15$), and (iii) higher output damages from pollution stock. For the latter experiment we scale up the pollution damage term in equation (15) to $zd(X_t)$ and set $z = 1.5$ in the sensitivity analysis.

Table A2 shows that compared to the baseline calibration, the second-best emissions tax is lower with the lower substitutability between brown and green inputs and with the higher abatement cost (columns 1 and 2). These two parameters do not have quantitatively noticeable effects on the second-best differentiated macroprudential policies (columns 4 and 5). With the higher pollution damages (i.e., 5.3% of steady-state output in the unregulated economy) both the first and second-best emissions taxes are higher (columns 3 and 9) compared to the baseline. The larger climate damages also result in much smaller subsidy for brown loans (column 6) as the pollution externality is now quantitatively more important and the prudential regulator takes it into account more. In fact, when climate damages are large enough, e.g. when $z = 4$ which implies the steady-state damages of 13%, the Ramsey regulator imposes a positive tax (albeit small) on brown loans and subsidy on green.

F Robustness to preference specification

In the baseline calibration, the households' period utility function is of Greenwood-Hercowitz-Huffman (1988) (GHH) form, eliminating wealth effects on labor supply. This preference specification is commonly used in models with financial frictions to allow for reasonable fluctuations in labor hours without explicitly modeling price rigidities and labor market frictions that would otherwise significantly complicate the model (see e.g., Gertler et al. 2012 or Bianchi 2016). In this section, we confirm that all our main findings still hold under a utility function that is additively separable in consumption and (composite) labor hours and thus allows for wealth effects on labor supply:

$$U(C_t, L_t^g, L_t^b) = \frac{C_t^{1-\eta}}{1-\eta} - \varpi \frac{\left[\left(L_t^b\right)^{1+\rho_L} + \left(L_t^g\right)^{1+\rho_L}\right]^{\frac{1+\xi}{1+\rho_L}}}{1+\xi} \tag{F1}$$

After re-calibrating the model with these separable preferences, all the parameter values, except for the labor disutility parameter ϖ, remain the same as in the baseline calibration (see Table 2). We set the labor disutility parameter $\varpi = 7.7337$ to target the steady-state labor hours of $\frac{1}{3}$, as we did in the baseline calibration.

Table A3 shows the steady-state results under various policy scenarios, as in Table 2, but now with household preferences given by equation (F1). The results are very similar to our baseline findings with the GHH preferences.

Figures A13 through A16 focus on transition dynamics and Ramsey efficient dynamic policies under the separable utility function. Qualitatively, the results are the same as in our baseline calibration. Quantitatively, allowing for the wealth effect on labor supply smooths out the effects of shocks. During the transition to a low-carbon economy, households' labor supply does not fall as much as in the case with the GHH preferences, and this mitigates the fall in aggregate output. It is still the case that ambitious climate policy action, without macroprudential policies, triggers equity losses in the banking sector and disrupts credit supply. Banks are forced to pull back their lending from the green sector which lowers green capital in the short- to medium-term (Figure A13), similar to the baseline scenario (Figure 1). Macroprudential policy again alleviates the transition risk stemming from ambitious climate policy (Figure

A14).

Similarly, with the wealth effect on labor supply, the negative TFP shock has a milder effect on the economic activity and banks' net worth. This implies that, with financial frictions, the second-best Ramsey efficient tax falls by less under the separable utility function compared to the baseline GHH preferences (Figure A15). The Ramsey-efficient second-best dynamic macroprudential policies are also very similar to the base-case results (Figure A16).

Table A1: Steady state: Additional variables

	No financial frictions		Financial frictions				
	No policy	Emissions tax only	No policy	Emissions tax only	Uniform macro-prudential policies only ($\tau^b = \tau^g$)	Differentiated macropru-dential policies only ($\tau^b \neq \tau^g$)	Emissions tax and uniform macropruden-tial policies
Consumption	1.124	1.131	1.076	1.080	1.116	1.116	1.131
Green output	0.914	0.924	0.848	0.855	0.902	0.908	0.924
Brown output	0.729	0.725	0.674	0.670	0.720	0.714	0.725
Green investment	0.299	0.301	0.256	0.257	0.291	0.295	0.301
Brown investment	0.199	0.196	0.171	0.168	0.194	0.190	0.196
Labor in green prod.	0.273	0.274	0.263	0.263	0.271	0.272	0.274
Labor in brown prod.	0.213	0.211	0.205	0.204	0.212	0.211	0.211
Pollution stock	1171.4	1089.4	1155.6	1089.4	1168.6	1166.9	1089.4

Note: This table shows the steady state values of selected variables in the economies with and without financial frictions under different policy scenarios. All variables are in arbitrary model units.

Table A2. Steady state: Sensitivity to parameters

	Financial frictions								
	Emissions tax only			Differentiated macroprud. only			Emissions tax and uniform macroprud.		
	$\rho_Y = 1.2$	$\theta_1 = 0.15$	$z = 1.5$	$\rho_Y = 1.2$	$\theta_1 = 0.15$	$z = 1.5$	$\rho_Y = 1.2$	$\theta_1 = 0.15$	$z = 1.5$
Emissions tax ($ per ton)	13.5	9.0	21.3	0	0	0	16.8	17.3	24.7
Tax on brown assets (%)	0	0	0	-0.15	-0.14	-0.11	-0.22	-0.22	-0.22
Tax on green assets (%)	0	0	0	-0.22	-0.22	-0.22	-0.22	-0.22	-0.22

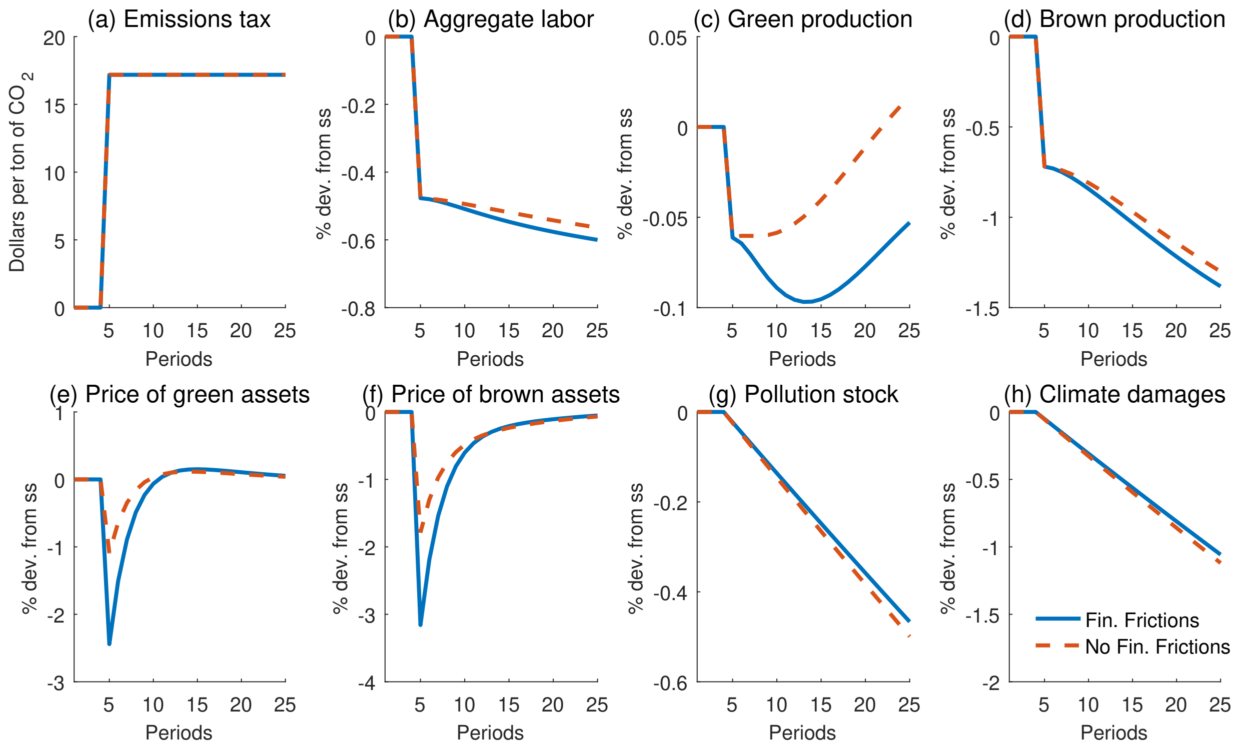
Note: This table shows sensitivity of Ramsey-efficient policies to different parameters in the economy with financial frictions. Parameter ρ_Y controls the elasticity of substitution between green and brown goods. θ_1 controls the cost of abatement, and z is the scalar controlling output damages from pollution; That is, for this sensitivity exercise we use z to scale the damage function as $zd(X_t)$.

Table A3: Steady state: Separable preferences

	No financial frictions		Financial frictions				
	No policy	Emissions tax only	No policy	Emissions tax only	Uniform macro-prudential policies only ($\tau^b = \tau^g$)	Differentiated macropru-dential policies only ($\tau^b \neq \tau^g$)	Emissions tax and uniform macropruden-tial policies
Emissions tax ($ per ton)	0	16.6	0	14.5	0	0	16.6
Tax on brown assets (%)	–	–	0	0	-0.20	-0.15	-0.22
Tax on green assets (%)	–	–	0	0	-0.20	-0.22	-0.22
Aggregate output	1.576	1.577	1.502	1.503	1.566	1.566	1.577
Climate damages (%)	3.68	3.13	3.61	3.13	3.67	3.66	3.13
Emissions	0.709	0.434	0.674	0.434	0.704	0.698	0.434
Banks' net worth	–	–	3.410	3.376	3.792	3.788	3.831
Green credit spread (%)	0	0	0.225	0.225	0.028	0.000	0
Brown credit spread (%)	0	0	0.225	0.225	0.028	0.075	0
Welfare loss (% CV)	0.61	0	1.18	0.67	0.59	0.58	0

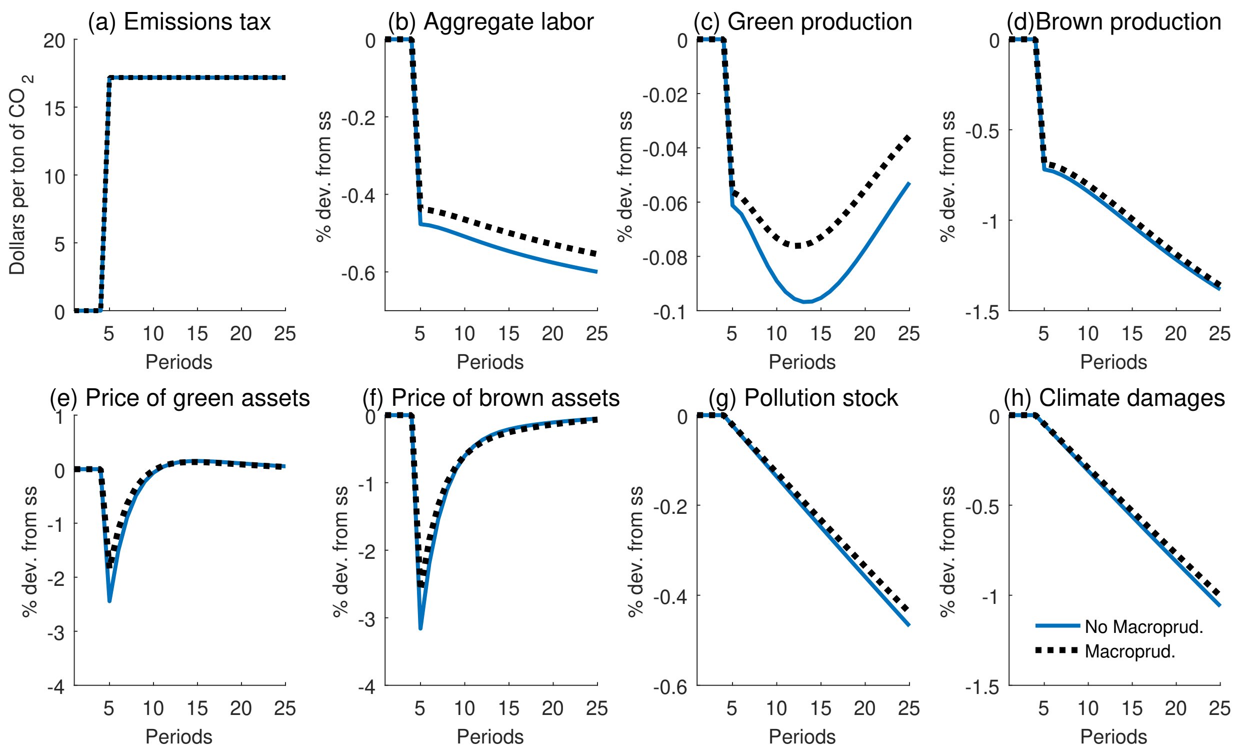
Note: This table shows the steady state values of selected variables in the economies with and without financial frictions under different policy scenarios. The units of the emissions tax are dollars per ton of CO_2, based on the calibration described in the text. Tax rates on banks' assets and credit spreads are in percentages. Climate damages are in percent of output. Welfare loss is in terms of compensating consumption variation relative to the first-best allocations. All other variables are in arbitrary model units. The households' utility function is given by equation (F1).

Figure A1: Transition to a low carbon economy: Additional variables



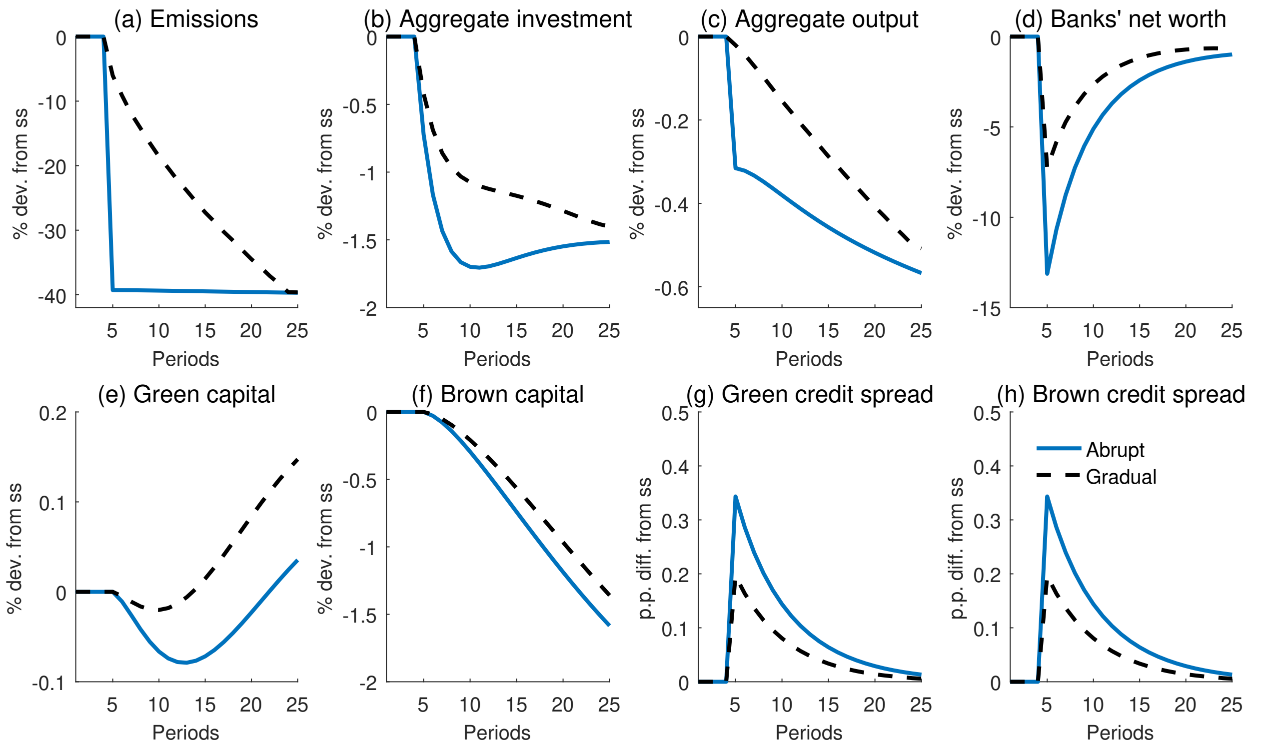
Note: This figure plots the transition dynamics of additional variables in response to the same path of the emissions tax as in Figure 1. Each simulation begins at the no-policy steady state under the given model.

Figure A2: Transition to a low carbon economy with macroprudential policy: Additional variables



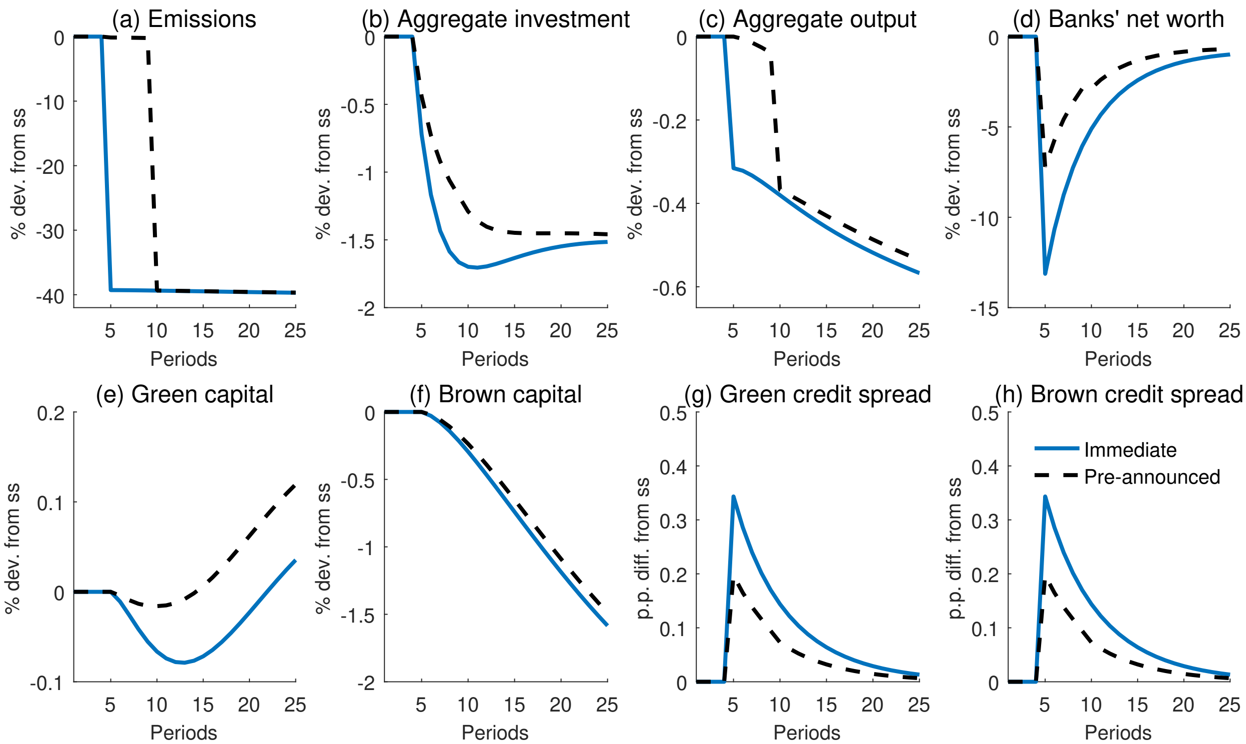
Note: This figure plots the transition dynamics of additional variables in response to the emissions tax introduction in the economies with and without macroprudential policy. Each simulation begins at the steady state with no emissions policy under the given model.

Figure A3: Transition dynamics: Abrupt versus gradual "ramp-up" approach



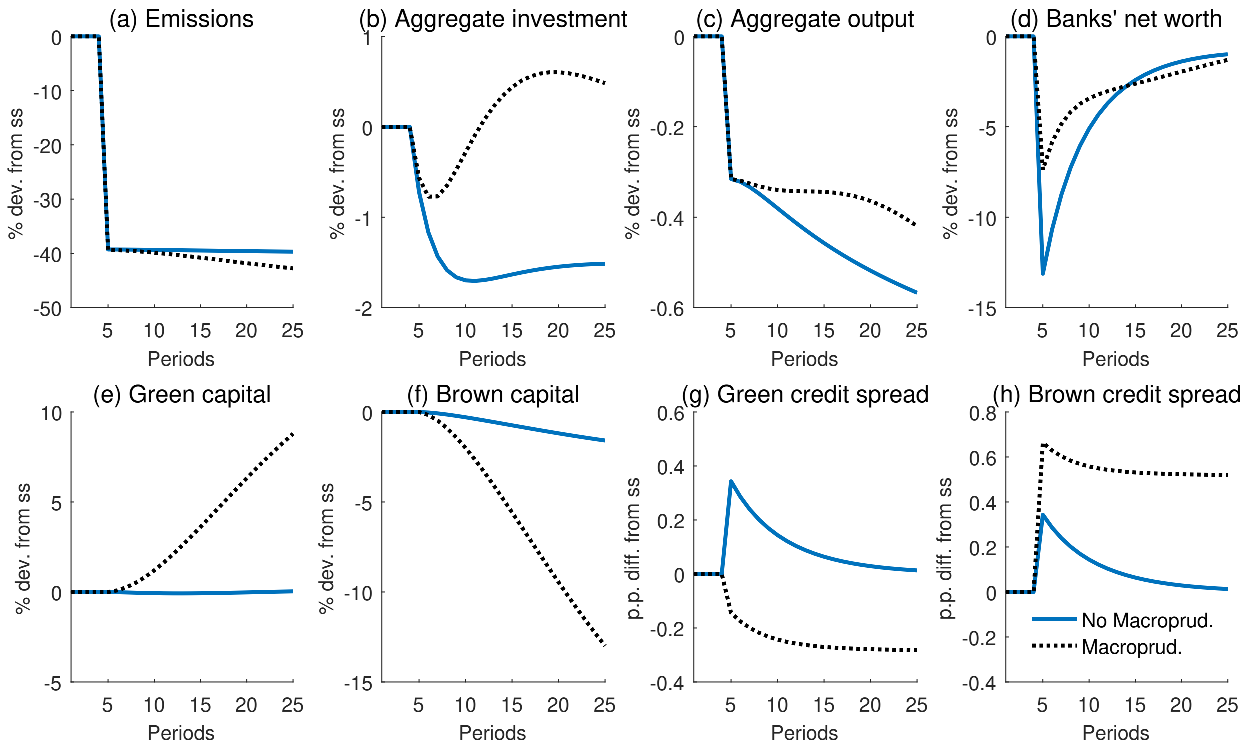
Note: This figure plots the transition dynamics in response to an unanticipated introduction of the permanent emissions tax of about 17 dollars per ton of CO_2, gradually introduced over 20 periods, in the economy with financial frictions. Each simulation begins at the identical no-policy steady state.

Figure A4: Transition dynamics: Immediate versus pre-announced implementation



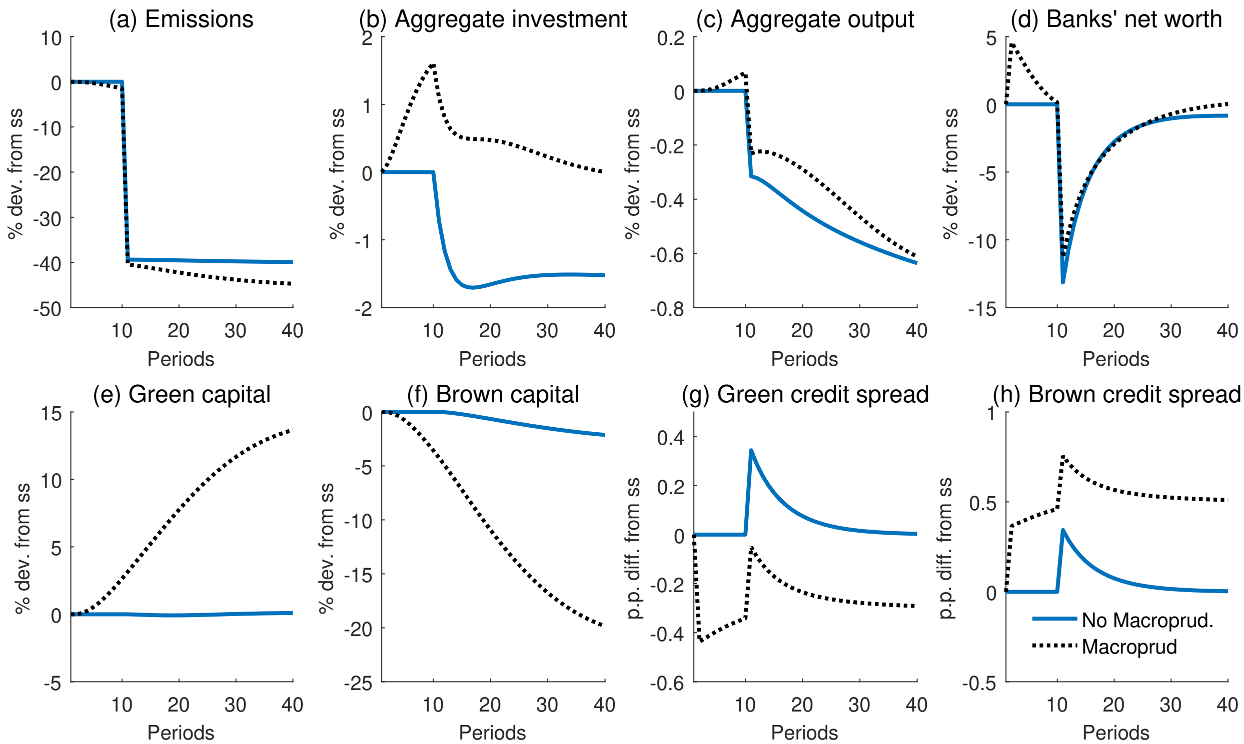
Note: This figure shows the transition dynamics in response to an introduction of a permanent emissions tax of about 17 dollars per ton of CO_2, which is announced in period 5 but does not go into effect until period 10, in the economy with financial frictions. Each simulation begins at the identical no-policy steady state.

Figure A5: Transition dynamics: Simultaneous macroprudential policies



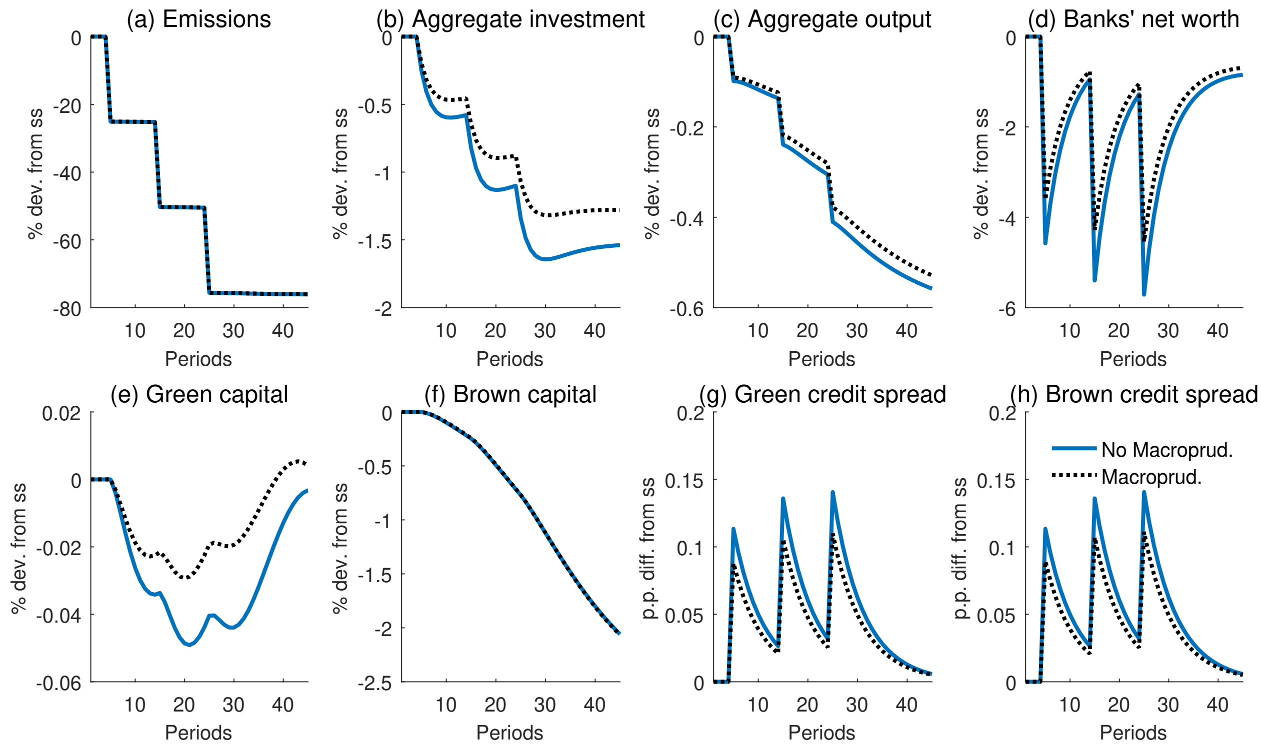
Note: This figure plots transition dynamics in response to an unanticipated introduction of the permanent emissions tax of about 17 dollars per ton of CO_2, along with a simultaneous introduction of macroprudential policies of the same magnitude as those presented in Figure 2. Each simulation begins at the steady state with no emissions policy under the given model.

Figure A6: Transition dynamics: Sequential implementation of policies



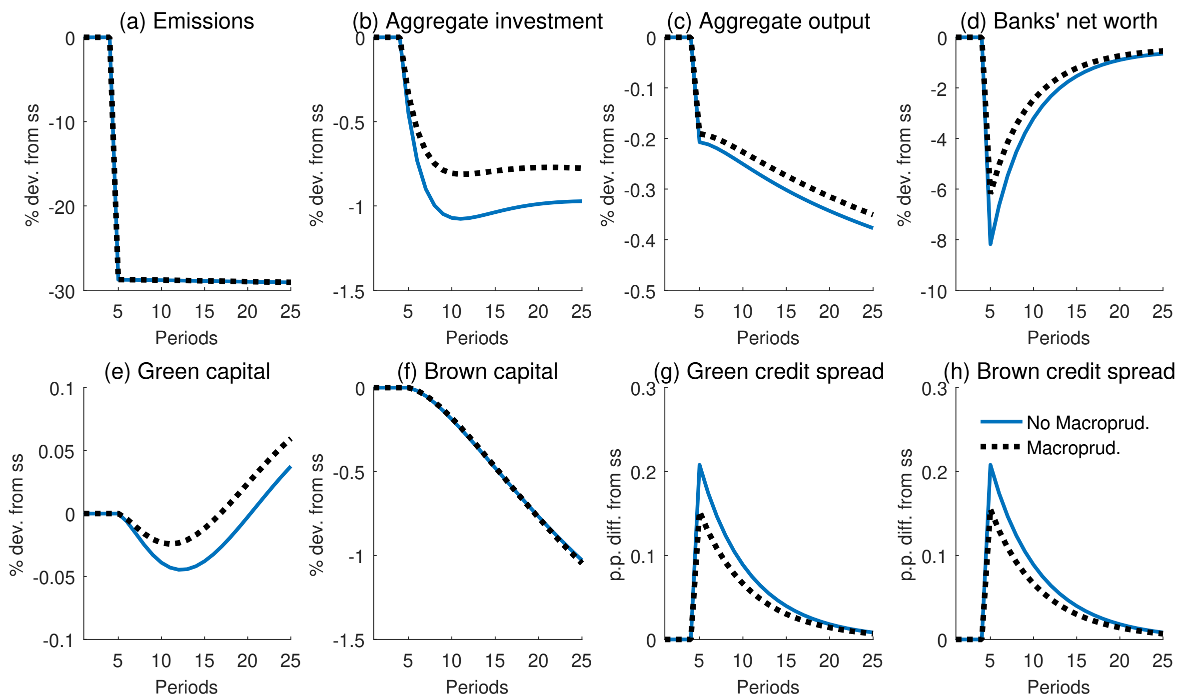
Note: This figure plots transition dynamics in response to an unanticipated introduction of the permanent macroprudential policies in period 2 and the permanent emissions tax in period 11. The magnitudes of the policies are the same as in Figure 2. Blue solid lines depict the case when only the emissions tax is introduced in period 11, but no macroprudential policy is enacted beforehand. Each simulation begins at the identical no-policy steady state.

Figure A7: Stochastic emissions tax



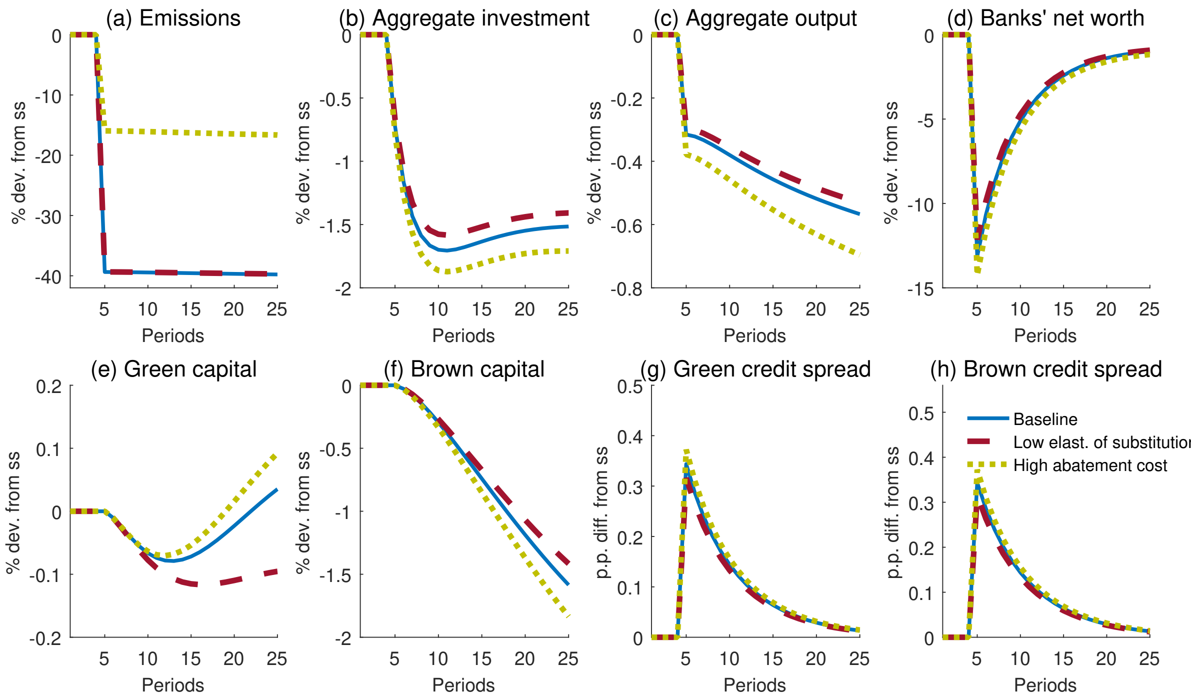
Notes: This figure plots the stochastic simulations when the economy is hit by a sequence of emissions tax shocks (in periods 5, 15, and 25). In these simulations emissions tax τ_t^e is assumed to follow the following stochastic AR(1) process: $\tau_t^e = (1-\rho_\tau)\,\tau_{ss}^e + \rho_\tau \tau_{t-1}^e + \sigma_\varepsilon \varepsilon_t, \quad \varepsilon_t \sim \mathcal{N}(0,1)$ with $\rho_\tau = 0.9999$ and $\sigma_\varepsilon = 0.01$. Each simulation begins at the steady state under the given model.

Figure A8. Transition dynamics to a low carbon economy: Low steady-state pollution stock



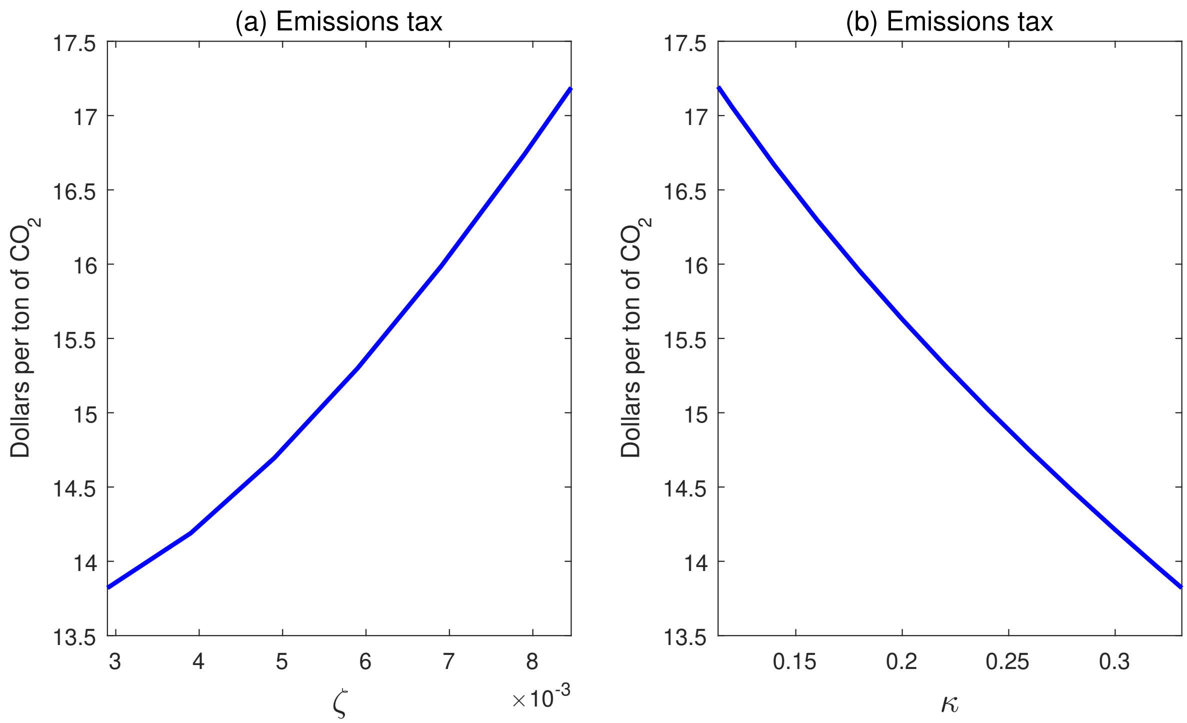
Note: This figure plots transition dynamics to a low carbon economy in the model with financial frictions with and without macroprudential policies, when we calibrate the steady state of the model to the current atmospheric carbon stock. In the low carbon stock calibration, we assume that the steady state pollution stock in the model corresponds to 851 GtC. The first best efficient tax in this case is 0.0116 (or about 10 dollars per ton of CO_2). The effects of the climate policy shock are qualitatively similar to the baseline calibration. Quantitatively the effects are smaller because of the lower carbon tax. Each simulation begins at the steady state with no emissions policy under the given model.

Figure A9: Transition dynamics to a low carbon economy: Sensitivity to parameters



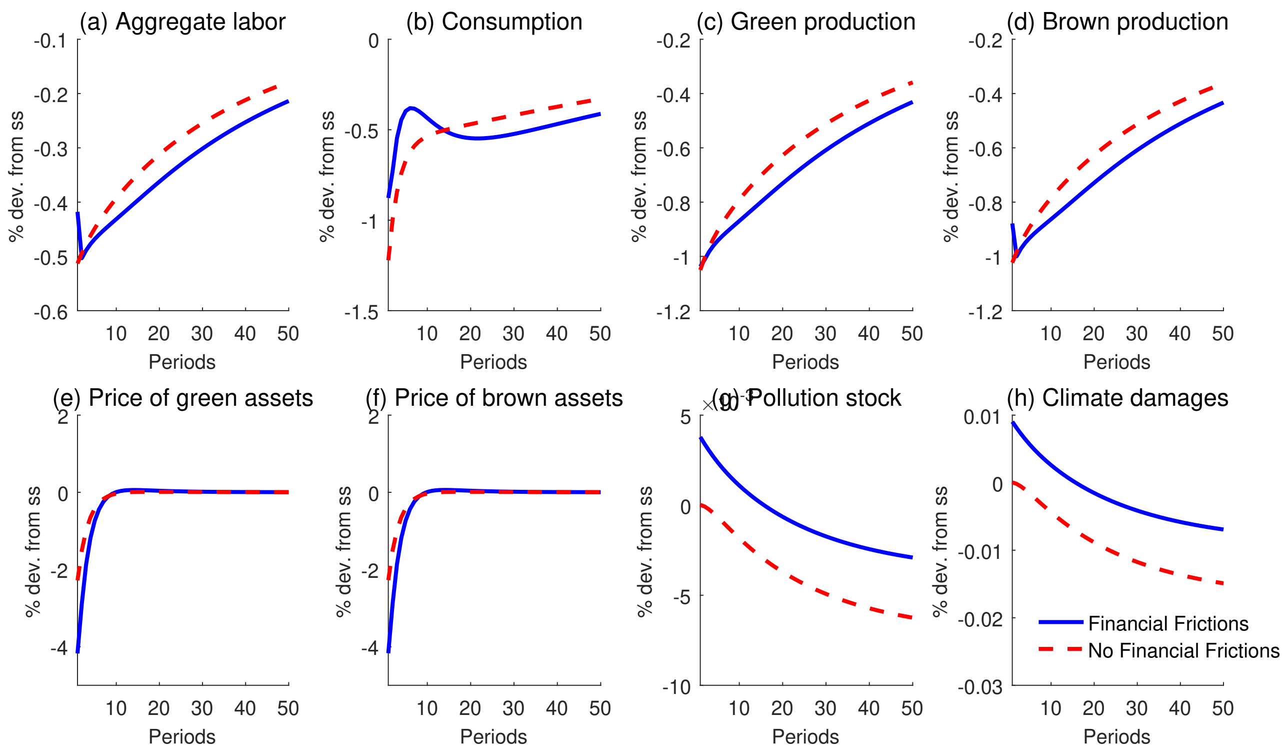
Note: This figure compares the baseline transition dynamics in the model with financial frictions (i.e., Figure 1, solid lines) to the case with the low elasticity of substitution between green and brown inputs ($\rho_Y = 1.2$), and high abatement cost ($\theta_1 = 0.15$). The path of the emissions tax in all the scenarios is the same as in Figure 1. Each simulation begins at the steady state with no emissions policy under the given model.

**Figure A10: Second-best steady-state emissions tax:
Sensitivity to parameters controlling financial frictions**



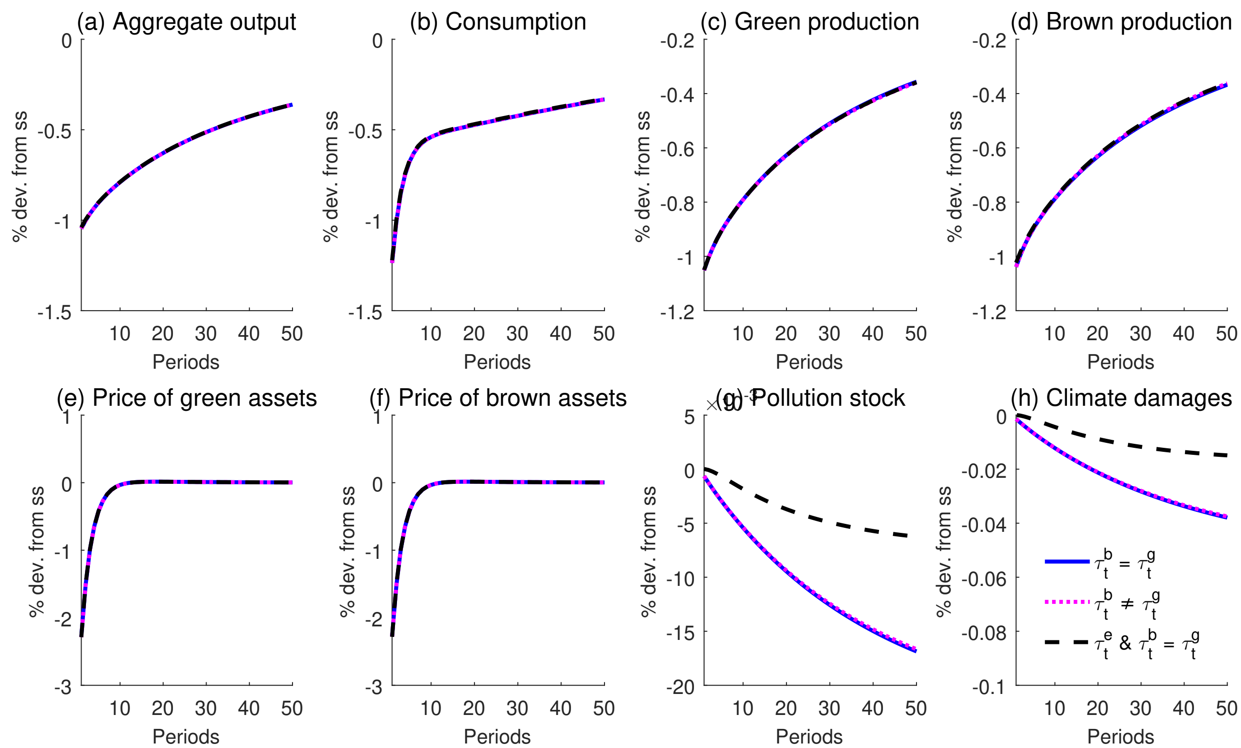
Note: This figure plots the second-best steady-state value of the emissions tax when varying either the banks' transfer parameter (ζ) or the agency problem parameter (κ) from their base-case values of 0.0029 and 0.3313, respectively.

**Figure A11: The Ramsey-efficient dynamic emissions tax:
Additional variables**



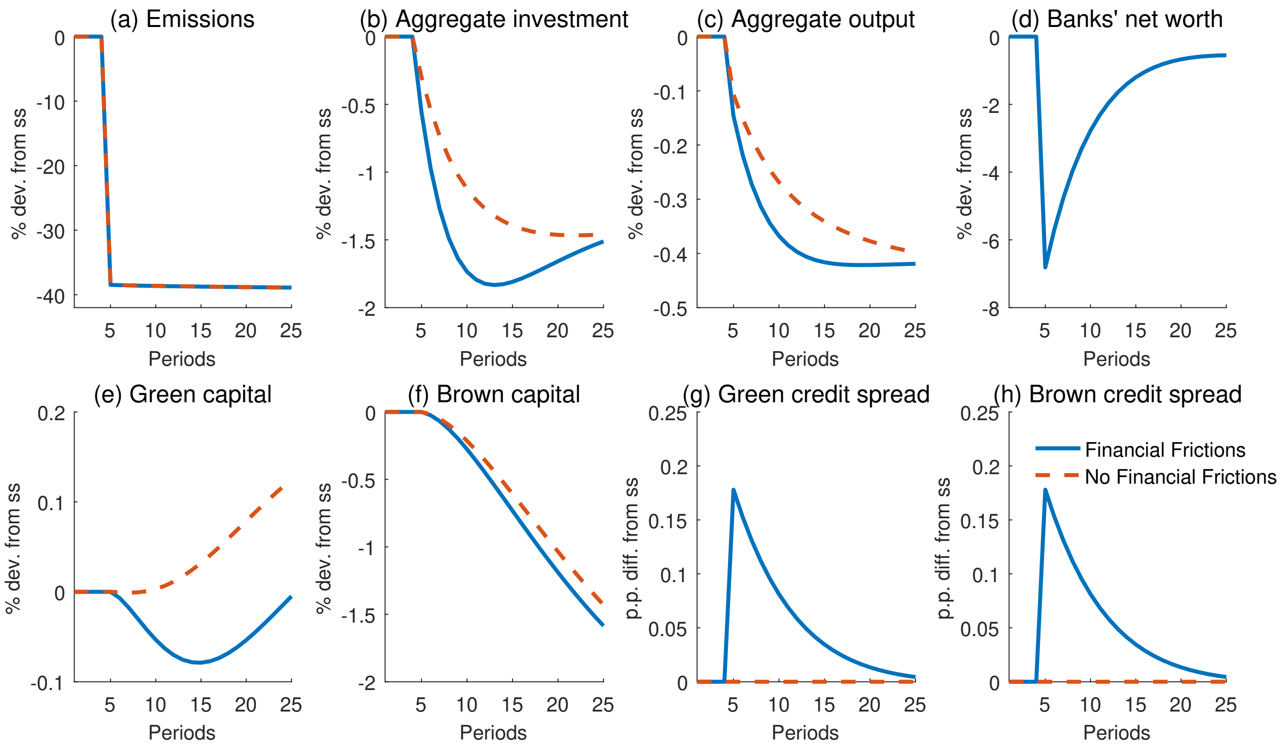
Note: This figure plots the impulse responses of additional variables to the same TFP shock as in Figure 3 under the Ramsey-efficient emissions tax policy in the economies (i) with financial frictions (solid lines) and (ii) without financial frictions (dashed lines). Each simulation begins at the steady state that includes the Ramsey-efficient emissions tax under the given model.

Figure A12: Ramsey-efficient dynamic policies under different sets of instruments: Additional variables



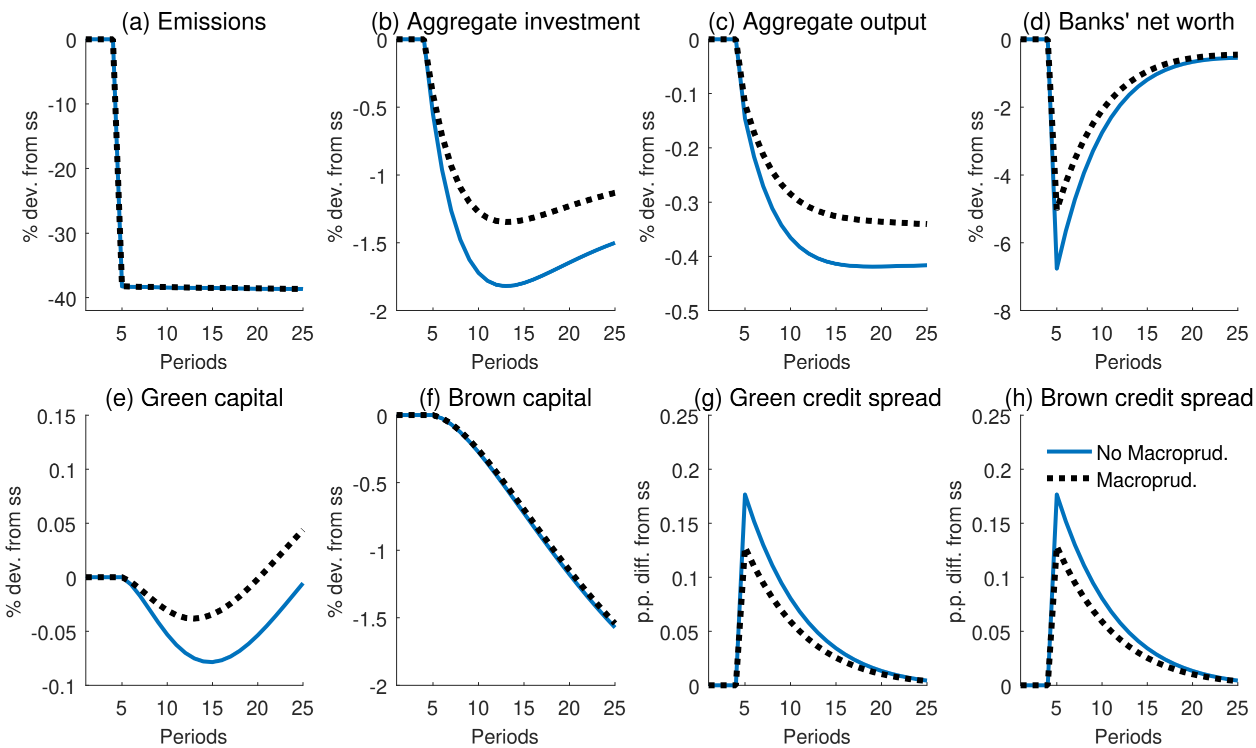
Note: This figure plots the impulse responses of additional variables to the same TFP shock as in Figure 4 under Ramsey-efficient policies with different sets of available instruments. Each simulation begins at the steady state that includes the specified policy combination.

Figure A13: Transition dynamics to a low carbon economy: Separable preferences



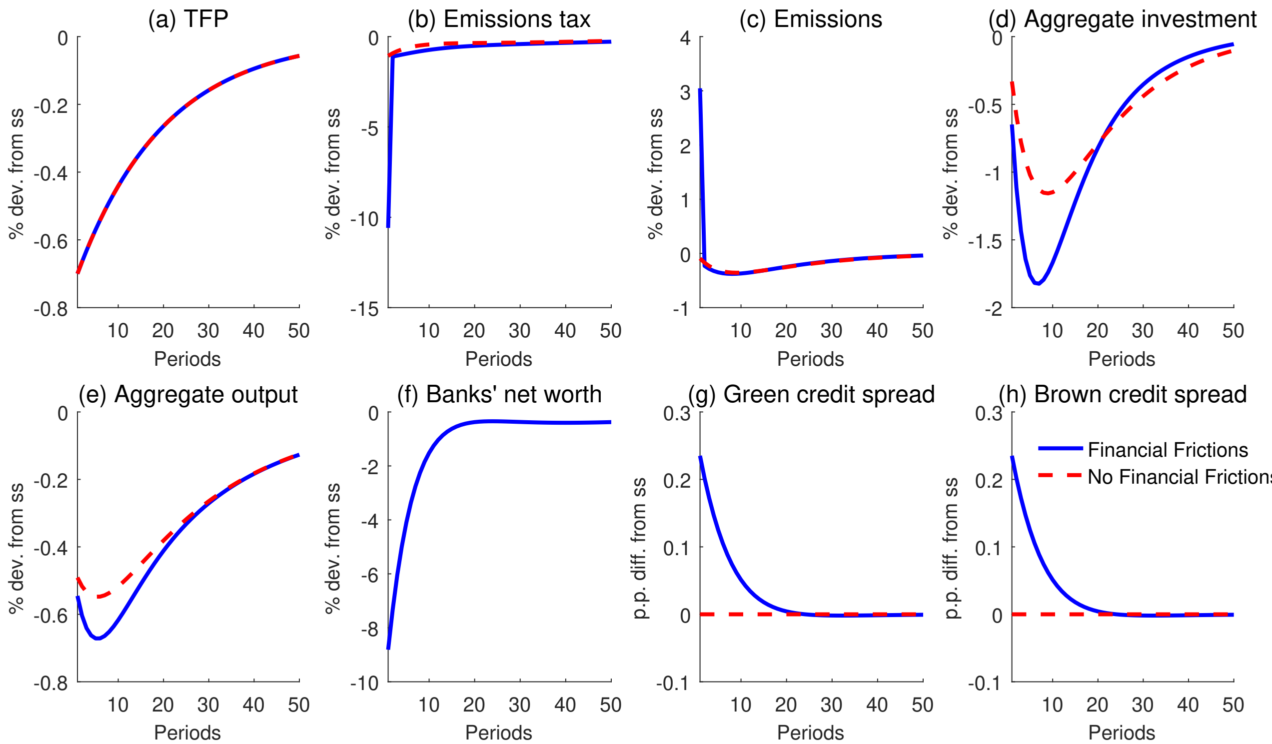
Note: This figure shows the transition dynamics to a low carbon economy in the models with and without financial frictions when the households' preferences are given by equation (F1). Each simulation begins at the steady state with no emissions policy under the given model.

Figure A14: Transition to a low carbon economy with macroprudential policy: Separable preferences



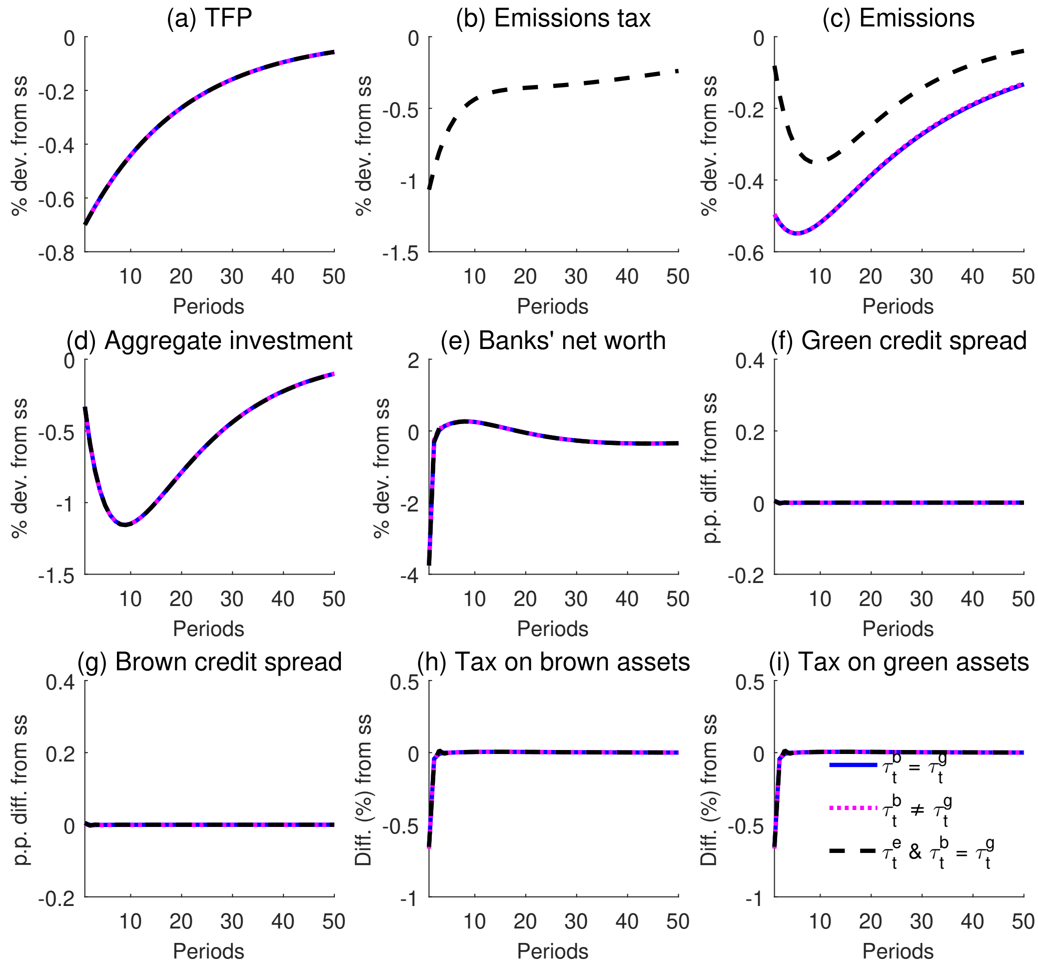
Note: This figure plots the transition dynamics in the model with financial frictions to the same emissions tax shock as in Figure A11 under two scenarios: (i) No macroprudential policy (solid lines); (ii) with macroprudential policy (dashed lines). Deviations are calculated relative to the respective initial steady states. The households' preferences are given by equation (F1). Each simulation begins at the steady state with no emissions policy under the given model.

Figure A15: The Ramsey-efficient dynamic emissions tax: Separable preferences



Note: This figure plots the impulse responses to a one-standard-deviation negative TFP shock under the Ramsey-efficient emissions tax policy in the economies (i) with financial frictions (solid lines) and (ii) without financial frictions (dashed lines). The households' preferences are given by equation (F1). Each simulation begins at the steady state that includes the Ramsey-efficient emissions tax under the given model.

A16: Ramsey-efficient dynamic policies under different sets of instruments: Separable preferences



Note: This figure plots the impulse responses to a one-standard-deviation negative TFP shock in the model with financial frictions under the Ramsey-efficient policies when (i) only uniform tax on banks' assets ($\tau_t^b = \tau_t^g$) is available (solid lines); (ii) only differentiated taxes on banks' brown (τ_t^b) and green (τ_t^g) assets are available (dotted lines); (iii) emissions tax (τ_t^e) and a uniform tax on banks' assets ($\tau_t^b = \tau_t^g$) are available (dashed lines). The households' preferences are given by equation (F1). Each simulation begins at the steady state that includes the specified policy combination.