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**ROLE OF BANK LENDING IN
FINANCING GREEN PROJECTS:
A DYNAMIC STOCHASTIC GENERAL
EQUILIBRIUM APPROACH**

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Abstract

This paper develops an environmental dynamic stochastic general equilibrium (E-DSGE) model with heterogeneous production sectors. In particular, the model comprises some low-carbon emission firms that finance their investments and production only through banking loans, and high-carbon emission firms that finance their investments either with bank loans or by issuing equities. Moreover, government imposes intensity targets to reduce pollution, and high-carbon emission firms buy permits to allow their production. The model studies the transmission mechanism of technology, monetary, and financial shocks and finds that only a positive financial shock to green firms can boost production and credit for the green sector. A financial shock can be interpreted as the borrowing capacity of firms in terms of tightening or relaxing the enforcement of collateral constraints. In contrast, a positive technology shock and easier monetary policy lead only to a short output on impact, but in the longer term green firms experience losses. Later, the paper analyzes the impact of several macroprudential policies and finds that only differentiated capital requirements can help to sustain green financing.

Keywords: E-DSGE model, environmental policy, green financing, macroprudential policy

JEL Classification: E32, E50, Q43, H23

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1. INTRODUCTION

During the last decade, policy makers have put a lot of effort into enhancing green financing with the main purpose of achieving economic growth coupled with environmental policies that aim to reduce pollution and greenhouse gas emissions. The Paris Agreement stipulated in 2015 that the global average temperature should be maintained below 2°C. This climate change strategy implies a shift to low-carbon investments to allow firms to produce different technology with a view to achieving low greenhouse gas emissions. However, green energy sources are expensive and could lead to losses for companies using renewable resources. There are two major barriers associated with green energy projects: a) a lower rate of return compared to fossil fuel projects; b) a higher risk of investment compared to fossil fuel projects (see Yoshino and Taghizadeh-Hesary 2018). Because of the associated risk and due to the Basel capital requirements, many banks are not interested in lending to the green energy sector. Hence we need to look for various financing tools and methods (banking and nonbanking solutions) in order to secure the flow of funds and growth in the green energy sector.

In order to reduce emissions, academics and policy makers have suggested the imposition of prices on carbon dioxide and other greenhouse gases either through price instruments (i.e. a carbon tax) or quantity instruments (i.e. cap and trade). In the case of a carbon tax, end consumers support the cost because the cost for producing the final good will increase due to the higher carbon tax. As a result, the supply of goods decreases and the equilibrium price increases. In the case of a cap-and-trade system, producers buy pollution permits in order to emit carbon, otherwise they incur an abatement cost to reduce emissions. If the abatement cost is less than the price to buy a permit, then the producers will prefer to face the abatement cost. In both cases, the production cost increases, supply decreases, and the price of the final good increases. Given such a higher production cost, specific investments in green sectors are essential to develop a green transformation in the production sector. The green sector requires a sustainable financial environment in order to make the transition towards a real sustainable environmental production process.

In general, difficulty in accessing external financing is the main obstacle for producers, and these financial constraints are exacerbated for the green sector, as the private sector is reluctant to invest as it fears the environmental risk. In this context, green financing will play a central role in allocating resources to sustainable investments. Moreover, the current unsustainable environment can generate imbalances in the real economy as environmental damages (e.g. floods and droughts) can affect price stability through their impact on food and energy prices, and consequently have a negative impact on production. Such environmental risks can lead to market distortions and losses for financial institutions when they provide credit. In order to reduce carbon emissions and maintain financial stability, a green macroprudential framework can offer alternative policies to achieve this goal by providing incentives for banks to lend more to firms producing below low-carbon emissions.

This paper aims to develop an environmental dynamic stochastic general equilibrium (E-DSGE) model with heterogeneous production sectors and evaluate possible macroprudential policies with the goal of supporting green financing. DSGE models are useful for identifying the source of uncertainty in shock-driven business cycles. Further, DSGE models can be used by policy makers in choosing policy instruments after the uncertainty is identified. In the context of climate change, E-DSGE models can be implemented by introducing uncertainty due to abatement costs, environmental tax

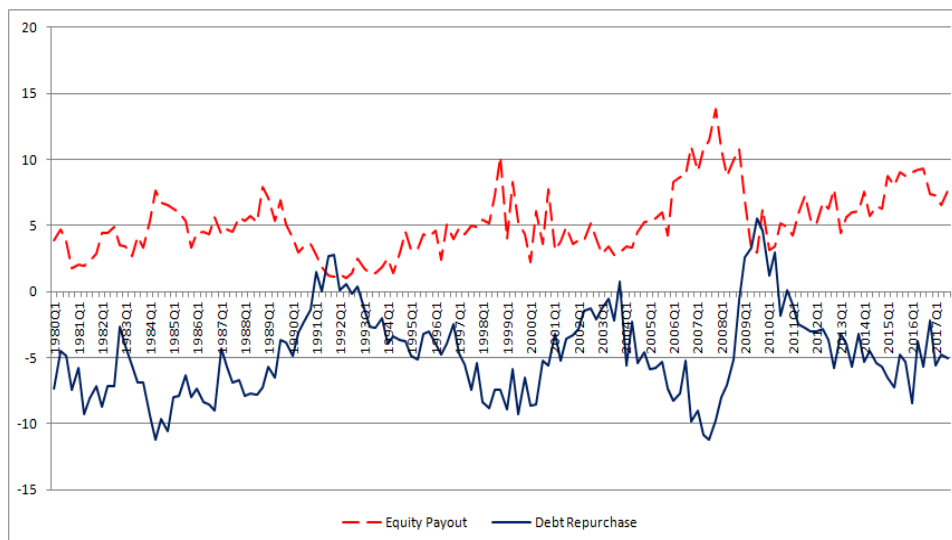
policy, and cap and trade that drives economic fluctuations as emissions tend to increase during expansions and to decrease during recessions. Vasilev (2018) has developed an environmental real business cycle model for Bulgaria and studied the transmission mechanism of a carbon tax and the use of government spending on abatement costs. Vasilev (2018) finds that the model performance increases by imposing certain environmental regulations, such as by-product reduction of pollution.

Xu, Xu, and Lu (2016) developed an E-DSGE model calibrated to the People's Republic of China (PRC) for the period between 1978 and 2014. They find that the introduction of environmental policies leads to economic loss and taxes might encourage firms to participate in emission-cutting activities.

In particular, I develop an E-DSGE model to evaluate the transmission mechanism of several sources of macroeconomic uncertainty such as productivity, monetary, and financial shocks in a setup that includes policies to reduce greenhouse gas emissions. Investment in low-carbon production will require a large amount of purchasing investment goods: production of energy from renewable sources, improvement of energy efficiency in buildings and transportation, management of natural capital, waste management, water management, sustainable agriculture, and others. Given the upfront costs of investments – particularly high in the case of renewable energy production – firms are typically unable to finance them through their own savings and thus need access to external finance. This paper will focus on the role of bank lending in financing low-carbon investment, as bank loans are the most important source of external finance for firms. In particular, the relevance and feasibility of implementing “green” macroprudential monetary policies to expand the amount of credit flowing to low-carbon activities will be assessed. Can macroprudential policies encourage green financing? What tools can be implemented in order to achieve this?

The model differentiates low- from high-carbon emission firms in terms of external finance sources and the environmental regime adopted. Bank loans are the primary and only source of finance for representative firms producing below low-carbon emissions. Moreover, such firms make use of renewable energy in the production process. On the other hand, high-carbon businesses are subject to an extra cost in the form of an emission intensity target (i.e. an exogenous limit on emissions per unit of output produced). Alternative measures can be implemented through cap and trade or a carbon tax. In terms of financing, high-carbon businesses can finance their investment with bank loans or by issuing equities in the form of share capital. Therefore, high-carbon emission firms implement a strategy substitution between debt and equity. Usually debt is preferred to equity but firms' ability to borrow is limited by a collateral constraint, thus firms shift to equity financing. Figure 1 reports the net payments to equity holders and the net debt repurchases in the nonfinancial corporate and noncorporate sector for the US (see Jermann and Quadrini (2012) for data details). The figure reveals the existence of a negative correlation between equity payouts and debt repurchases, suggesting a strong substitutability between equity and debt financing.

Figure1: Financial Flows in the Nonfinancial Corporate and Noncorporate Sector in the US



Sources: Flow of Funds Accounts of the Federal Reserve Board. *Equity Payout* is given by the sum between “Net dividends of nonfarm, nonfinancial business” and “Net dividends of farm business,” minus the sum of “Net increase in corporate equities of nonfinancial business” and “Proprietors’ net investment of nonfinancial business.” *Debt Repurchase* is the “Net increase in credit market instruments of nonfinancial businesses.”

The model shows that aggregate productivity shocks and easier monetary policy lead to a short-lived positive effect on output for low-carbon emission firms. In the longer term, such firms suffer losses due to a lack of bank loans as the price of capital falls. On the other hand, when the price of capital is low, high-carbon firms also face a lower collateral value and can borrow less from banks, therefore they shift to equity to finance new investments. Only financial shocks can boost production for low-carbon emission firms. A financial shock can be interpreted as the borrowing capacity of firms in terms of tightening or relaxing the enforcement of collateral constraints. In the context of the low-emissions sector, a positive financial shock can also be interpreted as the facility to create innovative financial products to finance and insure the projects involved, such as “green bonds” or the emergence and expansion of green investment banks.

There is a growing literature on E-DSGE models and environmental policies. Angelopoulos,

Economides, and Philippopoulos (2010) analyze the impact of alternative environmental policy rules in a real business cycle model under a total factor productivity where emissions are a by-product of production, and only the government can engage in pollution abatement activity. Fischer and Springborn (2011) evaluate volatility and welfare costs by comparing cap and trade, carbon tax, and the intensity target in a dynamic stochastic general equilibrium model with one polluting intermediate input. Heutel (2012) determines an optimal emissions policy in a dynamic stochastic general equilibrium model with a pollution externality during phases of expansions or recessions. Annicchiarico and Di Dio (2015) analyze different environmental policy regimes in a new Keynesian model with nominal and real uncertainty to evaluate the transmission mechanism of shocks with the presence of nominal rigidities and a monetary authority. Unlike previous literature, this paper develops two productivity sectors where one representative firm produces low-carbon emissions while the other one produces high-carbon emissions but has to buy permits from the

government. Moreover, no paper has evaluated the implementation of potential macroprudential policies to support green financing, and no paper has studied the transmission channel of monetary policy shocks and financial shocks. This paper fills this gap.

The paper is organized as follows. Section 2 describes the DSGE model. Section 3 presents the theoretical impulse responses to productivity, monetary, and financial shocks, and evaluates several macroprudential policies. Section 4 concludes and provides policy recommendations.

2. THE THEORETICAL MODEL

The model consists of a representative household, final good firms, intermediate goods firms, capital producers, a banking sector, and two types of entrepreneurs. In particular, the production sector includes the presence of green firms producing low-carbon emissions and nongreen firms that produce high-carbon emissions. In order to prevent excess pollutant emissions, the latter is subject to limits on aggregate emissions in the form of taxes. Debt is the main financial vehicle for low-carbon climate resilient (LCR) firms. The debt-to-equity ratio in overall infrastructure projects is about 70:30 (Dobbs et al. (2013)), while renewable energy financing shows a debt-to-equity ratio of around 75:25. Therefore the model assumes that firms producing low-carbon emissions can finance their activities only with bank loans, while high-carbon emission firms can also issue equities.

2.1 Households

The household decision is:

$$\max E_0 \sum_{t=0}^{\infty} (\beta_h^t)^t \left[\ln (C_{h,t}) - \frac{\tau}{1+\varphi} (H_t)^{1+\varphi} \right],$$

subject to the budget constraint:

$$C_{h,t} + \Theta_t(D_t) + q_t^E \Xi_t = W_t H_t + R_t^d D_{t-1} + (d_t + q_{t-1}^E) \Xi_{t-1} + F_t. \quad (2.1)$$

Households derive utility from consumption, $C_{h,t}$, and hours worked, H_t , and W_t is the real wage rate paid for household labor. D_t is the household's holding of real deposits with the banking sector at the beginning of time t , and R^d is the return on deposits in period t , which is known at time t . Ξ_t is the household's equity investment (private equity) in large firms at the beginning of time t , d_t is the equity payout paid by large firms, and q_t^E is the price of equity shares. F_t is net payoffs to the household from ownership of large firms. $\beta_h \in (0,1)$ is the subject discount factor. Households face a portfolio selection problem by choosing the level of deposit or equity to hold. Portfolio selection problems of nonrisk-neutral agents are generally solved in a mean-variance framework, in which the risk attitude and the risk relative to the expected mean matter. In DSGE models, such a problem requires an approximation of a higher order than the usual one because the portfolio choice is indeterminated in the deterministic steady state otherwise (e.g. Tille and Van Wincoop (2010); Devereux and Sutherland (2011)). In this model, we solve the portfolio selection problem by adding portfolio costs for

deposit as in Schmitt-Grohe and Uribe (2003) to induce stationarity. Therefore, $\Theta_t(D_t) = D_t + \frac{\kappa}{2}(D_t - \bar{D})^2$, where $\kappa > 0$ is the adjustment cost parameter.

2.2 Firms and Price Settings

The Final-Goods-Producing Firms.

The final good, Y_t , is produced by perfectly competitive firms using $Y_t(i)$ units of each type of intermediate good i and a constant return to scale, a diminishing marginal product, and a constant elasticity of substitution technology:

$$Y_t \leq \left[\int_0^1 Y_t(i)^{\frac{\xi-1}{\xi}} di \right]^{\frac{\xi}{\xi-1}}, \quad (2.2)$$

where $\xi > 1$ is the constant-elasticity-of-substitution parameter. The price of an intermediate good, $Y_t(i)$, is denoted by $P_t(i)$ and is taken as given by the competitive final-good-producing firms. Solving for cost minimization yields a constant-price-elasticity demand function for each goods type i that is homogeneous to degree one in the total final output, $Y_t(i) = \left[\frac{P_t(i)}{P_t} \right]^{-\xi} Y_t$, and the domestic price index $P_t = \left[\int_0^1 P_t(i)^{1-\xi} di \right]^{1/(1-\xi)}$.

The Intermediate Sector.

There is a continuum of monopolistically competitive firms indexed by $i \in [0,1]$ that produce intermediate goods, $y(i)$, using the following technology:

$$Y(i)_t = A_t A_{z,t} (H(i)_t)^{1-\alpha} K(i)_{t-1}^\alpha, \quad (2.3)$$

where

$$K(i)_t = \sigma K(i)_{H,t} + (1 - \sigma) K(i)_{L,t}, \quad (2.4)$$

with $K(i)_H^\sigma$ and $K(i)_L^{1-\sigma}$ being capital rented by high- and low-carbon emission entrepreneurs. Therefore $(1 - \sigma)$ is the share of utilized low-carbon emission firms' capital in utilized total capital.

A_t is an aggregate productivity shock, while $A_{z,t}$ is sector-specific productivity shock.

2.3 Capital Producers

Capital producers combine a fraction of the final goods purchased from retailers as investment goods, $I_{k,t}$, to combine it with the existing capital stock in order to produce new capital goods. In each period capital producers buy back the undepreciated capital stocks at real prices q_t^k .

Capital production is subject to an adjustment cost specified as $\frac{\psi_k}{2} \left(\frac{I_{k,t}}{K_{t-1}} - 1 \right)^2 I_{k,t-1}$, where ψ_k governs the slope of the capital producers' adjustment cost function. Capital producers choose the level of $I_{k,t}$ that maximizes their profits

$$\max_{I_{k,t}} q_t^k I_{k,t} - \left(I_{k,t} + \frac{\psi_k}{2\delta_k} \left(\frac{I_{k,t}}{K_{t-1}} - \delta_k \right)^2 K_{t-1} \right).$$

From profit maximization, it is possible to derive the supply of capital

$$q_t^k = \left[1 + \frac{\psi_k}{2\delta_k} \left(\frac{I_{k,t}}{K_{t-1}} - 1 \right) \right], \quad (2.5)$$

where q_t^k is the relative price of capital. In the absence of investment adjustment costs, q_t^k is constant and equal to one.

The usual capital accumulation equation is

$$I_{k,t} = K_t - (1 - \delta_k)K_{t-1}. \quad (2.6)$$

2.4 Entrepreneurs

2.4.1 Green Firms: Low-carbon Emissions

There is a continuum $j \in [0,1]$ of entrepreneurs indexed by L that maximize consumption, as follows:

$$\max E_0 \sum_{t=0}^{\infty} (\beta_S^t) \ln (C_{L,t})$$

subject to the budget constraint:

$$C_{L,t} + W_t H_{L,t} + q_t^k K_{L,t} + R_t^L B_{L,t-1} = (1 - \delta)q_t^k K_{L,t-1} + Y_{L,t} + B_{L,t}, \quad (2.7)$$

and

$$Y_{L,t} = A_t A_{L,t} (H_{L,t})^{1-\alpha-\kappa} K_{L,t-1}^\alpha E_t^\kappa, \quad (2.8)$$

and a borrowing constraint:

$$B_{L,t} \leq \theta_t E_t \left[\frac{(1 - \delta)q_{t+1}^k K_{L,t}}{R_t^L} \epsilon_{f,t} \right]. \quad (2.9)$$

$\beta_s^t < \beta_h^t$; this means that entrepreneurs producing low-carbon emissions are more impatient than households, therefore they prefer to consume rather than to save in the present. B_L is the level of borrowing via banking loans, and R^L is the repayment interest rate. θ_t represents the loan-to-value ratio and $\epsilon_{f,t}$ is a financial shock that can relax or tighten the borrowing constraint.

Firms produce goods by combining capital, K_L , labor, H_L , and renewable energy, E_t . Moreover, firms can experience an aggregate technology progress, A_t , or a green sector-specific technology shock, $A_{L,t}$.

2.4.2 Nongreen Firms: High-carbon Emissions with Limits on Pollution

Firms decide on capital and labor inputs before the arrival of the technology shock, A_t . Part of the capital is financed through the equity investment from the household sector at the beginning of each period, denoted by Ξ_t , and the rest is borrowed from the banking sector, $B_{L,t}$; therefore,

$$K_{H,t} = B_{H,t} + \Xi_t. \quad (2.10)$$

The consumer's contribution to capital acquisition can be viewed as private-equity investment with possible gains/losses to be settled at the end of the period, once the shocks are realized. Note that we assume that firms are owned by the household. From the household's viewpoint, the leverage ratio of firm i is given by $v_i = K_{H,t}/\Xi_t$. The share of capital financed by the banking sector is then given by

$$B_{H,t} = \left(\frac{v_i - 1}{v_i}\right)K_{H,t}. \quad (2.11)$$

Firms acquire their entire capital stock, $K_{H,t}$, at the beginning of each period t . It is also assumed that firms transfer any excess profits to the household sector.

Large firms maximize the cum-dividend market value of the $V(s; K_{H,t}, B_{H,t})$, as in Jermann and Quadrini (2012). For each firm i , $K_{H,t}$ and $H_{L,t}$ are derived by solving the following optimization problem:

$$V(s; K_{H,t}, B_{L,t}) = \max \{ \Xi_t + E_t \beta^E V(s; K_{H,t+1}, B_{H,t+1}) \}$$

subject to

$$R_t^L B_{H,t-1} + W_t H_{H,t} + q_t^k K_{H,t} + \varphi(\Xi_t) = Y_{H,t} + q_t^k (1 - \delta) K_{L,t-1} + B_{H,t}. \quad (2.12)$$

and

$$Y_{H,t} = A_t A_{H,t} (1 - \Gamma(M_t)) (H_{H,t})^{1-\alpha} K_{H,t-1}^\alpha, \quad (2.13)$$

where $\varphi(\Xi_t) = \Xi_t + \frac{\kappa}{2}(\Xi_t - \bar{\Xi})^2$. To formalize the rigidities affecting the substitution between debt and equity, we assume that the firm's payout is subject to a quadratic cost. $\kappa \geq 0$, and $\bar{\Xi}$ is a coefficient equal to the long-run payout target (steady state). Γ is an increasing and convex function in the form of taxes on pollution emitted, and M_t is the current level of pollution stock. Emissions are proportional to output as follows:

$$M_t = (1 - \delta_M)M_{t-1} + \varphi Y_{H,t}, \quad (2.14)$$

where δ_M expresses a decay fraction of pollution that naturally decays, while φ represents the emission per unit of output, $Y_{H,t}$. In contrast, Vasilev (2018) introduces an environmental policy for Bulgaria in the form of a time-varying proportional environmental tax on revenue.

Banks' loans are also subject to collateralized constraints, such as:

$$B_{H,t} \leq \theta_t E_t \left[\frac{(1 - \delta) q_{t+1}^k K_{H,t}}{R_t^L} \right]. \quad (2.15)$$

2.5 Banking Sector

We assume there is a banking sector that receives at time t deposits from domestic households, D_t , and makes loans to both firms, $B_{L,t}$ and $B_{H,t}$. This setup is similar to that of Kollmann, Enders, and Müller (2011).

Therefore

$$B_t = B_{L,t} + B_{H,t}.$$

The banking sector faces a capital requirement that the capital ($B_t - D_t$) cannot be smaller than a fraction γ of the bank's assets B_t .

The banking sector maximizes

$$\max E_0 \sum_{t=0}^{\infty} \beta_b^t \ln(C_{b,t}),$$

subject to the flow of funds

$$C_{b,t} + R_t^d D_{t-1} + B_t + \Gamma(D_t, B_t) = D_t + R_t^L B_{t-1}$$

and

$$D_t \leq (1 - \gamma)B_t,$$

where $C_{b,t}$ denotes the banker's consumption (dividends) and β_b is its discount factor; $B_t = B_{L,t} + B_{H,t}$ represents one-period bank loans extended to low- and high-carbon emission firms in period t and $\Gamma > 0$ denotes the real marginal *operating* cost of collecting deposits and extending loans. $\Gamma(D_t, B_t) = \Gamma_D D_t + \Gamma_B B_t$.

We assume that the bank can hold less capital than the required level, but that this is costly (e.g. because the bank then has to engage in creative accounting). The excess capital is given by

$$x_t = (1 - \gamma_t)B_t - D_t$$

Table 1: Bank Balance Sheet

Assets	Liabilities
Loans to Green Firms ($B_{L,t}$)	Domestic Deposits (D_t)
Loans to Nongreen Firms ($B_{H,t}$)	Bank Capital (x_t)

2.6 Market Clearing Conditions

$$H_t = \sigma H_{L,t} + (1 - \sigma)H_{H,t}$$

$$K_t = \sigma K_{L,t} + (1 - \sigma)K_{H,t}$$

$$Y_t = \sigma Y_{L,t} + (1 - \sigma)Y_{H,t}$$

$$C_t = C_{h,t} + C_{L,t} + C_{H,t} + C_{b,t}$$

As in Kollmann, Enders, and Müller (2011), we assume that the bank purchases the resources that are necessary for deposits and lending, $\Gamma(D_t + B_t)$, from the final good producer, and that 50% of the resource cost $\phi(x_t)$ is borne in final good units. As Γ and ϕ are physical inputs used by the banking firm, and they have to be subtracted from the final good production when computing GDP. Hence, Home GDP, denoted by Y_t , is

$$Y_t = Z_t - \Gamma(D_t + B_t) - \frac{1}{2}\phi((1 - \gamma)B_t - D_t)$$

and the final market clearing condition is:

$$Y_t = C_t + I_t + \frac{\kappa}{2}(\Xi_t - \bar{\Xi}_t)^2.$$

2.7 Exogenous Shocks

Aggregate technology shock:

$$\ln A_t = \rho_A \ln A_{t-1} + \varepsilon_{A,t}, \quad (0.1)$$

Firm-specific technology shock:

$$\ln A_{k,t} = \rho_A \ln A_{k,t-1} + \varepsilon_{A,t}, \quad (0.2)$$

Financial shock:

$$\ln \epsilon_{f,t} = \rho_\epsilon \ln \epsilon_{f,t-1} + \varepsilon_{\epsilon,t}, \quad (0.3)$$

2.8 Parameterization

The model is parameterized based on Jermann and Quadrini (2012). The model is parameterized at a quarterly frequency. Discount factors are set such that $\beta_h = \beta_s = \beta_b = 0.9825$, implying that the annual steady-state return from holding equities is 7.32%.

The Cobb-Douglas parameter for the capital share in the production for intermediate goods, $K(i)$, is set to 0.36, the depreciation rate of capital, δ_k , is set to 0.025, and the adjustment cost parameters for investment is set equal to 0.001. In terms of collateral, we parameterize the LTV parameters θ_L and θ_H to 0.7. These parameters ensure a steady-state value of banks loans to GDP of about 30%. The portfolio adjustment cost parameter is set equal to 0.25.

The required bank capital ratio is calibrated to be equal to 0.08. This value reflects the rules defined under Basel II and Basel III, which require that the total risk-weighted capital requirement, which is defined as total (Tier 1 and Tier 2) capital divided by total risk-weighted assets, is at least 8%. The discount factor is set equal to the savers' discount factor. The bank operating cost coefficient is set equal to 0.0018, while the cost on banks' excess capital is set to 0.1264, which is similar to Kollmann, Enders, and Müller (2011).

3. THEORETICAL RESULTS

3.1 Impulse Responses

The following section reports on impulse responses to exogenous shocks.

Figure 2 shows impulse responses to an aggregate technology shock when no policy on emission is imposed (solid line) and when the government limits the emissions that high-carbon firms can emit (circle line). An aggregate technology shock increases on impact output for green and nongreen firms. However, the prospect of high productivity leads to a higher equity price issued by nongreen firms, while the price of capital decreases. Nongreen firms decide to pay out net equity and borrow more to finance their investments and production. On the other hand, the lower price of capital decreases the collateral value of green firms, which will have less access to credit. As a result, after an initial increase, the output for green firms decreases. When an emission policy is implemented, the responses of output, loans, and equity prices are lower than in the case of no policy. As the price of capital decreases less, the decrease in loans for green firms is less pronounced.

Figure 2: Aggregate Technology Shock

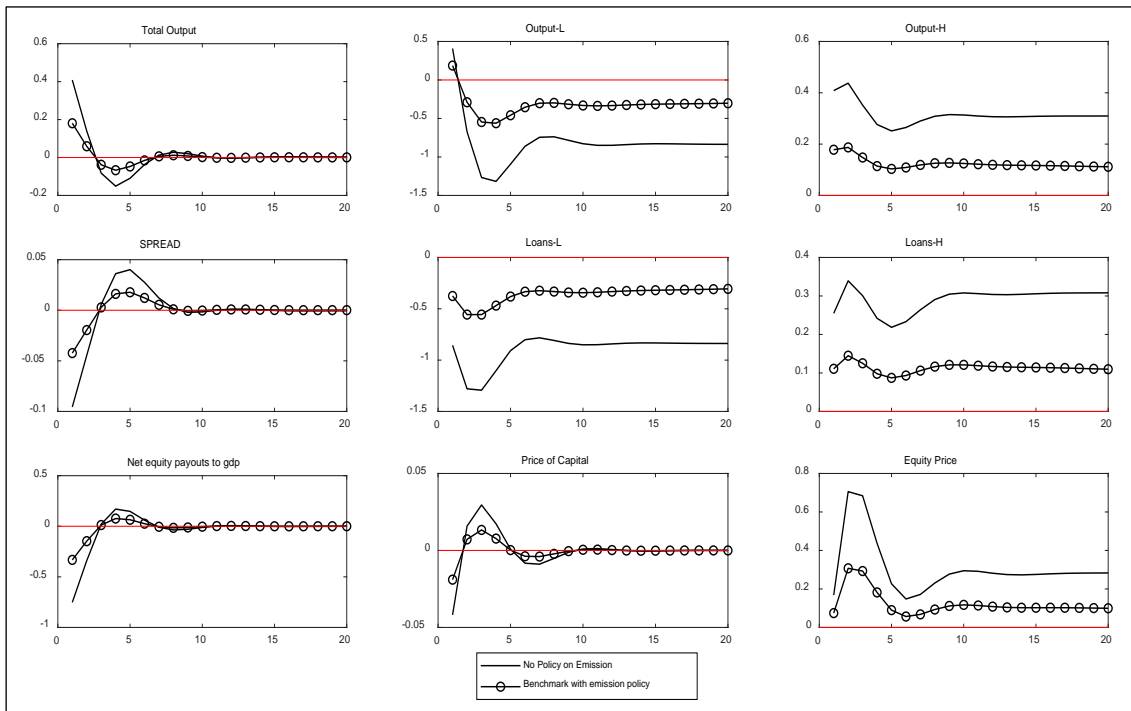


Figure 3: Monetary Policy Shock

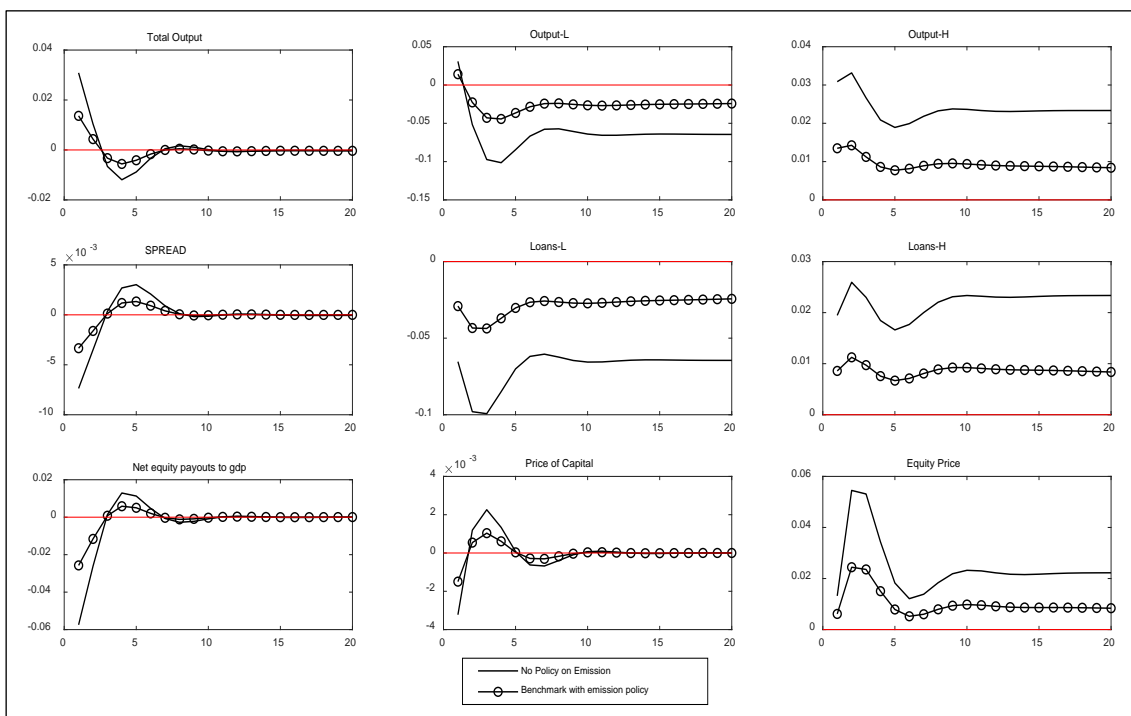
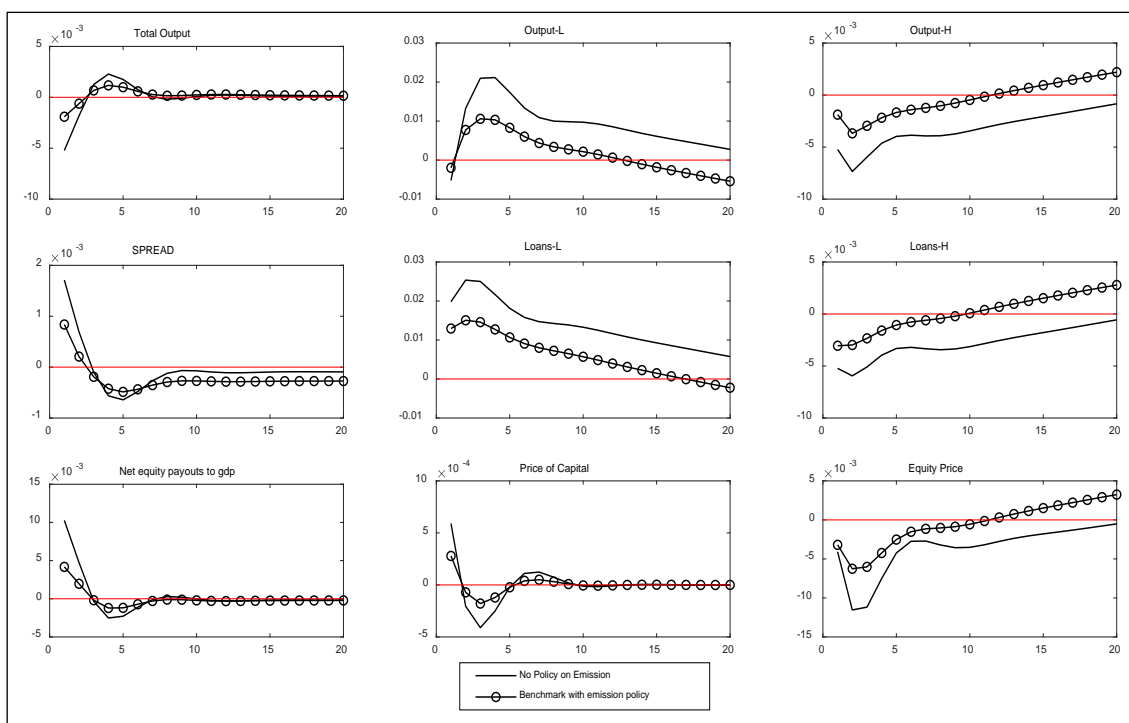


Figure 3 shows impulse responses to an expansionary monetary policy shock. A lower interest rate leads to higher output for nongreen firms that decide to pay out net equity and borrow more as the cost of borrowing is lower. However, banks are more willing to extend credit to nongreen rather than green firms, because the latter are considered

riskier. As a result, green firms obtain less credit and their output increases only for one period, but later decreases because of less access to external finance. The overall output increases but then decreases to reflect the drop in the green sector production. Similar results can be found in Annicchiarico and Di Dio (2015), who show that an increase in the policy rate leads to a short-term reduction in output with a quick increase after a few quarters.

Figure 4: Credit Shock



3.2 Policy Experiments

This section analyzes the impact of some macroprudential policies with the aim of supporting the production of below low-carbon emissions. Figure 5 compares the impact of exogenous shocks when higher capital requirements are imposed on banks based on the last Basel II and Basel III agreements (point-dotted line), which impose a minimum capital ratio of 8% (Basel II) plus an additional 2.5% (Basel III), and a countercyclical loan-to-value (LTV) ratio applied only to low-carbon firms (starred line). A countercyclical LTV ratio is a policy aimed at increasing the LTV when there is a sector slowdown or at decreasing it when there is an excess borrowing in order to avoid asset bubbles. In all cases, these policies reduce the quantitative impact of every shock. However, these policies are able to reduce the negative impact on green firms when technology and monetary shocks hit the economy, but they are not strong enough to boost the investment and production under low-carbon emissions. Compared to the countercyclical loan-to-value ratio of green firms, a higher capital requirement is more effective in reducing the negative impact on this sector.

Table 2 reports the stochastic volatility implied in the model simulation under the policy rules adopted. The environmental policy to reduce pollution with an intensity target applied to output per unit greatly reduces business cycle fluctuations. However, a countercyclical loan-to-value ratio that responds to variations of total output generates

the same stochastic volatility as in the case of the implementation of intensity target. Therefore, a macroprudential policy that aims to allow for higher LTV during economic slowdown doesn't help low-carbon firms to obtain higher credit to finance their new investments. Nevertheless, the financing behavior of high-carbon emission firms negatively spills over on green firms as the price of collateral falls, and even if those firms can gain access to higher LTV, the asset price is still too low to obtain higher credit. In contrast, a higher capital requirement for banks leads financial intermediaries to allocate their supply of credit in order to guarantee a certain bank return and the negative impact of the price of capital is reduced, thereby bringing down the volatility of business cycle fluctuations.

Table 2: Stochastic Volatility

Variable	No Policy	Intensity Target	LTV	CapReq	Diff.CapReq
Total Output	0.4207	0.1855	0.1855	0.1365	0.0502
Output-L	1.9415	0.8467	0.8467	0.6267	0.2186
Output-H	0.3996	0.1738	0.1738	0.13	0.0548
Consumption	0.0528	0.0227	0.0227	0.016	0.0061
SPREAD	0.2754	0.1218	0.1218	0.1024	0.0498
Loans-L	1.1119	0.4879	0.4879	0.3655	0.1216
Loans-H	0.1842	0.0794	0.0794	0.0575	0.0278
Net-equity	1.8977	0.837	0.837	0.6056	0.2193
Price of Capital	0.1318	0.0595	0.0595	0.0416	0.0119
Equity Price	0.4351	0.1896	0.1896	0.136	0.0338

Notes: "CyC LTV" denotes a macroprudential policy that targets only low-carbon emission firms and borrowing is constrained by a countercyclical loan-to-value ratio relative to changes in total corporate indebtedness. "Cap Req." denotes a banking capital requirement where an extra 2.5% is added to the standard 8% implied by Basel II and Basel III. "Diff. Cap Req." denotes differentiated capital requirements applied to low- and high-carbon emission firms.

Policy makers and central banks can implement several policy tools to incentivize green lending and allocate credit away from environmentally harmful activities. Some recent macroprudential tools suggest policy to differentiate rediscount rates and capital or reserve requirements that affect the money multiplier in order to affect investment decisions and allocate credit toward green investments. However, if central banks adjust the capital requirement for banks for their green financings, it might endanger the financial stability because of accumulating riskier assets for banks. Hence, besides policy for differentiating the capital requirement ratio for the green sector, central government needs to establish green credit guarantee schemes in order to cover the risk of banks, to keep the stability in the financial system (Yoshino and Taghizadeh-Hesary 2016).

Figure 6 shows that standard macroprudential policies are not enough to avoid losses experienced by low-carbon emission firms under macroeconomic uncertainty. Therefore, the model evaluates the impact of the implementation of green differentiated reserve requirements as suggested in Chandavarkar (1987), Rozenberg et al. (2013), and Campiglio (2016). Reserve requirements have the power to influence the banks' ability to create credit and distribute the stock of money into the economy. Lower reserve requirements allow banks to increase their lending. In particular, Campiglio (2016) suggests that lower rates of banks' reserve on green assets would encourage green investments over conventional investments. In this paper, we propose a macroprudential policy that encourages the differentiation of capital requirements. In addition, it is important for the central banks or FSA to develop a comprehensive

supervision mechanism in order to monitor whether or not the excess capital of banks is really allocated to the green sector.

Figure 5: Policy Experiments

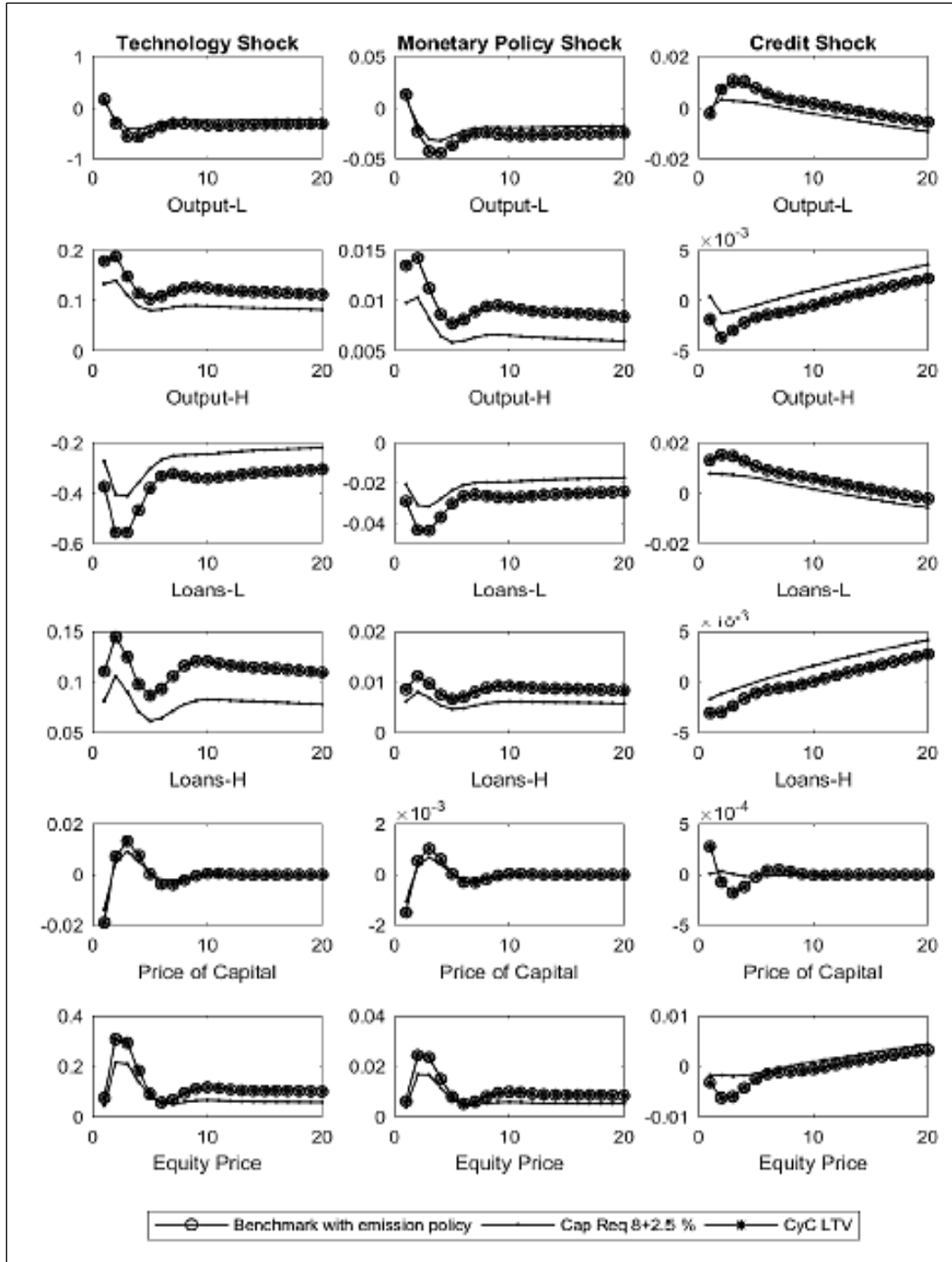
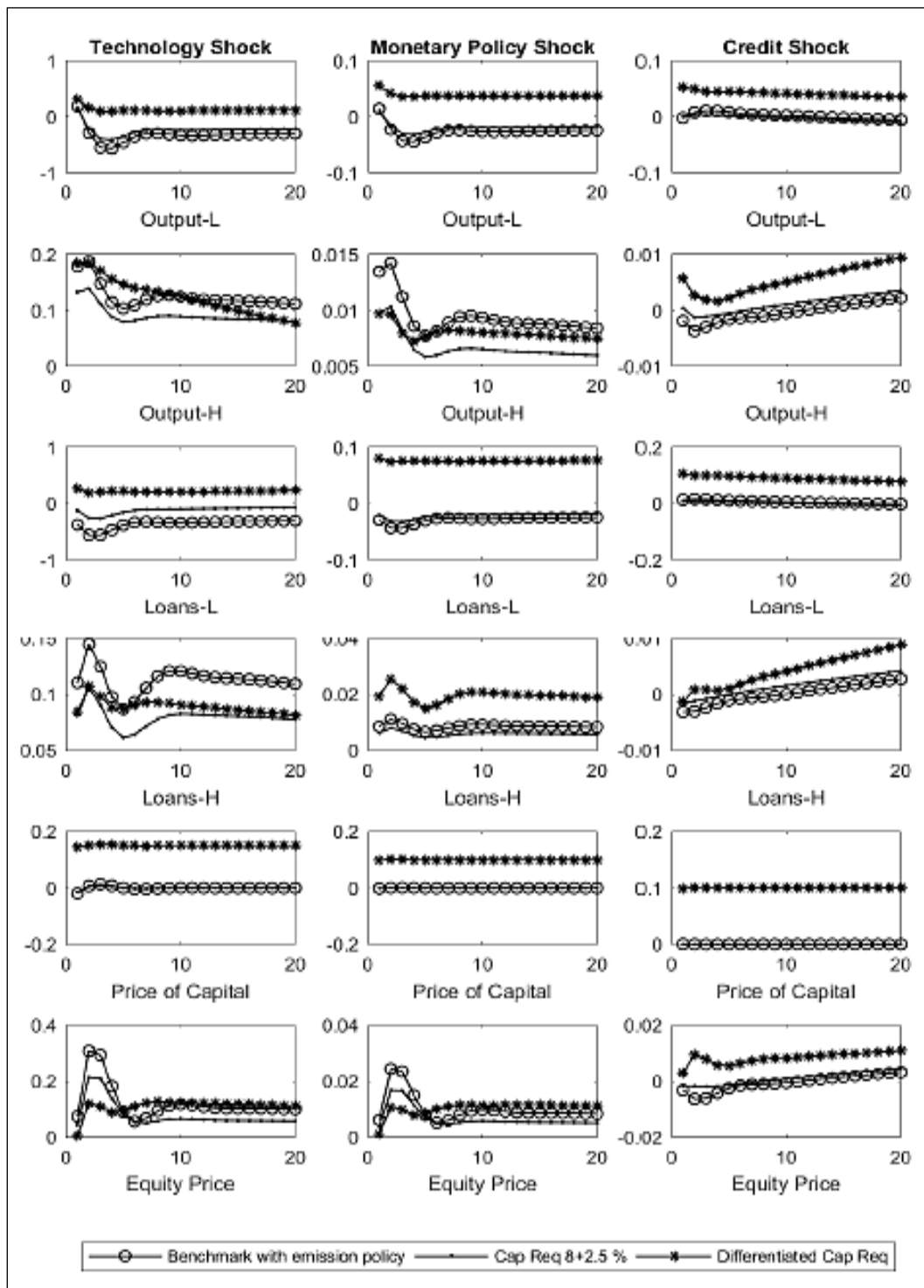
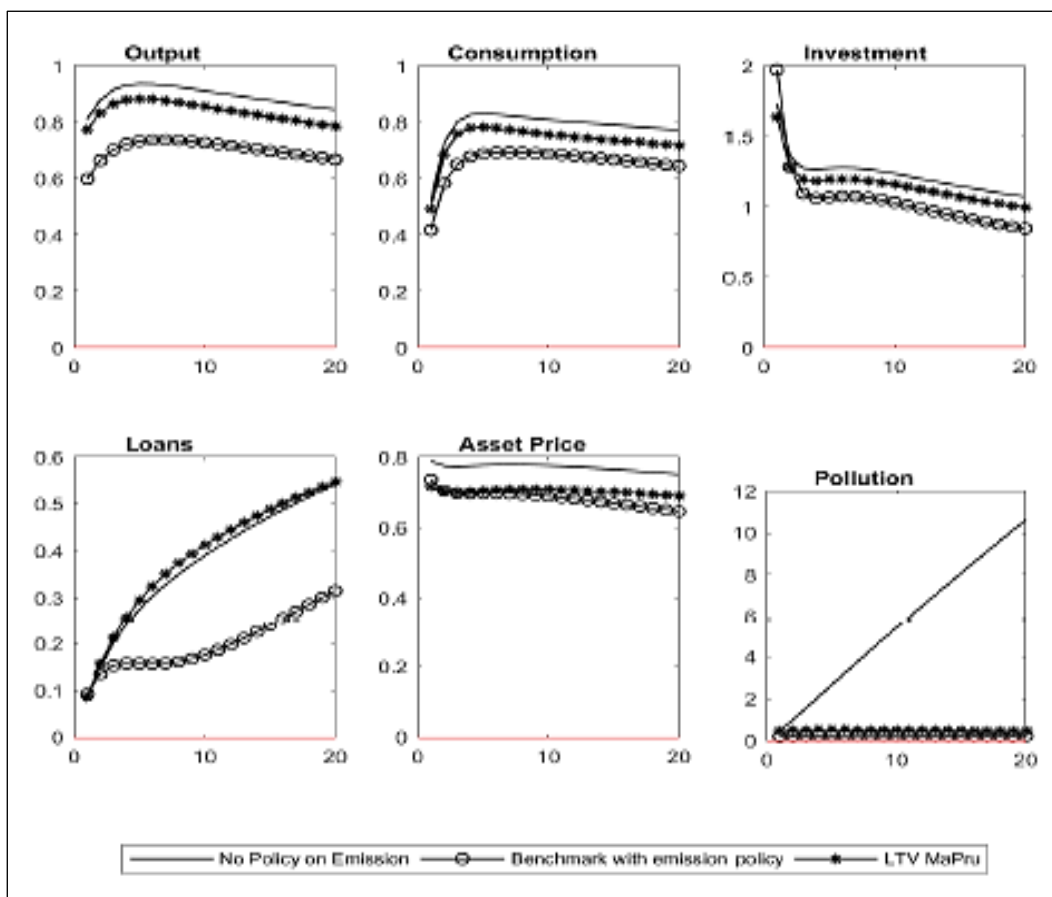


Figure 6: Policy Experiments



As with reserve requirements, different types of banks or different lending activities can imply different capital requirements. The minimum capital adequacy ratio imposed under Basel II (i.e. the ratio of a bank's capital to its risk-weighted assets) can directly affect the ability of financial institutions to extend credit. For instance, Basel III imposes a lower capital requirement for loans to small and medium enterprises (SMEs) in order to provide a differentiated treatment to SME financing compared to large enterprises. Similarly, the implementation of a policy that foresees lower capital requirements for loans to green firms and higher capital requirements to nongreen firms is evaluated. This policy should encourage banks to extend more credit to the former and less to the latter in order to protect the environment from excess pollution. Figure 6 shows that a macroprudential policy that differentiates capital requirements helps to avoid losses among green firms, as they can have easier access to credit from the banking sector. Moreover, the last column in Table 2 shows that such a policy damps business cycle fluctuations relative to other policies.

Figure 7: Technology Shock (Only Low-carbon Emission Firms)



3.3 Only Green Firms

It is worth comparing a case in which only green firms are present in the market. Figure 7 shows that an emission policy such as cap and trade or intensity target will decrease the quantitative impact in all macro variables when a positive technology shock hits companies producing low-carbon emissions. Similar results are found in Annicchiarico and Di Dio (2015). When a macroprudential policy relaxes the borrowing

constraint, firms have easier access to credit and can invest more in clean or renewable energy. However, the use of DSGE models with only one type of production sector as in Annicchiarico and Di Dio (2015) is limitative as Figure 7 showed that green firms experience only a short period increase in output. The increase in equity prices leads to a large drop in other asset prices, negatively affecting the collateral value in obtaining more credit from the banking sector. The transmission mechanism differs a lot.

4. CONCLUSIONS AND POLICY RECOMMENDATIONS

This paper develops an environmental dynamic stochastic general equilibrium (E-DSGE) model with heterogeneous production sectors. In particular, the model comprises some green firms producing below low-carbon emissions that finance their investments and production only through banking loans, and nongreen firms that produce high-carbon emissions and buy permits from the government to allow their production. The latter firms can finance their investments either with bank loans or by issuing equities. The model studies the transmission mechanism of technology, monetary, and financial shocks and finds that only a positive financial shock to green firms can boost production and credit for the green sector. In contrast, a positive technology shock and easier monetary policy lead only to a short output on impact, but in the longer term green firms experience losses. A second part of the paper analyzes the impact of several macroprudential policies and finds that only differentiated capital requirements can help to sustain green financing.

In order to commit to the 2015 Paris Agreement, a large number of initiatives have been launched with the aim of providing financial support for the transition to a green environment. Many of those initiatives, such as a carbon trading scheme and carbon tax, have been focused on reallocating existing private capital from institutional investors. However, results do not show a substantial achieved goal. Lately, many policy makers have been advocating the intervention of central banks in addressing climate change risk and to support green financing. To make the green transition phase successful, there is a need for financial regulators and central banks to coordinate their policies in order to guarantee that the credit and monetary system is in line with the transition to a green economy. Some central banks are recognizing that climate change is a potential risk for the stability of the financial system and economic growth. Climate change policy can negatively affect firms' financial position and asset price valuation, raising issues for financial stability.

The Bank of England has explicitly recognized that climate change can affect the safety and soundness of financial firms, with obvious implications for central banks. The Central Bank of the Netherlands and the Norges Bank have recognized that, even if the production of nongreen sectors does not represent a systemic risk, their financing exposure can turn into a potential systemic threat.

Central banks and financial regulators should consider alternative policy measures to mitigate environmental risk coupled with the major goal of enhancing green financing. Suggested measures include higher capital requirements for loans granted by nongreen economic activities, and lower capital requirements to support the transition to a green economy. Academic research also suggests the implementation of "green" quantitative easing (QE) by allowing central banks to directly purchase green bonds issued by green corporates. An alternative approach would be to purchase green bonds from development banks or green banks, such as the European Investment Bank.

In parallel with monetary policy, macroprudential regulations should take into account climate-related financial risks. The most obvious instrument would be the imposition of increased capital requirements against “brown” loans. Alternative macroprudential measures include the implementation of a “countercyclical buffer” that requires banks to hold increasing amounts of capital as the growth rate of lending to carbon-intensive sectors increases, or the lowering of requirements on green assets in order to encourage greener investments.

The Bank of Lebanon (officially the Banque du Liban) has introduced differentiated reserve requirement ratios by reducing the commercial bank’s obligatory reserve requirements by an amount equal to 100–150% of the loan value for a project under energy savings. The Central Bank of Brazil requires commercial banks to incorporate environmental and social risk in their governance framework and to evaluate these risks in the calculation of their capital needs. The Bank of Bangladesh has been providing additional liquidity to commercial banks lending to the green sector, while the Reserve Bank of India has implemented a minimum proportion of bank lending to flow to green financing. The Bank of Japan is offering subsidized priority loans to financial institutions via a loan support program to support environment and energy businesses.

However, few countries have engaged so far in the implementation of monetary and macroprudential tools in order to mitigate environmental risk and to support green financing. There is a need for urgent international cooperation to facilitate the transition phase to a below two-degree economy, compatible with the Paris Climate Change Agreement.

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