Inflation and income inequality in an open economy

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Abstract

This study explores the relationship between inflation and income inequality in an open-economy Schumpeterian growth model with heterogeneous households, firm-level innovation, and cash-in-advance constraints on R&D investment. We find that the relation between domestic inflation and inequality depends on the global real interest rate. Specifically, inequality monotonically increases with domestic inflation if the influence of a country's technology growth on the global real interest rate is low, while it displays a U-shaped pattern when the influence is sufficiently high. In contrast, foreign inflation always reduces domestic income inequality in the model by lowering domestic economic growth. These predictions are supported by our quantitative model calibrated to the U.S. and eurozone economies and empirical results using cross-country data.

JEL classification: D30; E41; O30; O40

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1 Introduction

The redistribution effect of monetary policy through inflation has received increasing attention by monetary economists. For instance, Doepke and Schneider (2006) examine the inflation-induced wealth redistribution among different groups of households in the U.S., as well as between foreigners and domestic households. Doepke, Schneider and Selezneva (2018) study the effect of an increase in inflation expectation on inequality and aggregate consumption through its effect on house prices. Chu, Cozzi, Fan, Furukawa and Liao (2019a) explore the effects of inflation on innovation and income inequality in a quality-ladder growth model.[1]

We contribute to the literature by examining this question in an open-economy framework. Previous studies in this strand of literature have mainly considered a closed-economy setting.[2] Given the increasing openness in the global economy, it is important to expand the study to an open-economy framework. We fill this gap in the literature and document novel results that potentially help to unveil the cross-country nexus between inflation and inequality.

We develop a two-country version of the Schumpeterian growth model in which economic growth and inequality are affected by the inflation in both countries. Following Klette and Kortum (2004), our model features firm-level innovation in terms of the number of product lines and a cash-in-advance (CIA) constraint on research and development (R&D) investment in each country.[3] Our choice of endogenous growth model is inspired by an important insight from the seminal work of Kuznets (1955) that inequality is intimately correlated with economic growth. In addition, the recent literature of endogenous economic growth demonstrates that R&D is the modern engine of growth in industrialized economies, following the pioneering work by Romer (1990). Therefore, it is critical to understand the impact of inflation on inequality through its effect on R&D activities and economic growth in an R&D-based model of endogenous growth. The CIA constraint in our model is motivated by the empirical studies that highlight the importance of liquidity constraints to R&D investment activities.[4] This CIA constraint on R&D, combined with an open-economy setting that permits international trade and financial markets, provides a rich framework under which inflation has sizable impacts on R&D investment, economic growth, and income inequality in both countries since the costs of inflation are transmitted between sectors not only within a country, but also internationally.

Our two-country model predicts that the relation between a country's income inequality and

[1]See Albanesi (2007a), Auclert (2019), Zheng (2020) and Zheng, Mishra and Yang (2020) for examples of other studies on this topic. The redistribution effect of monetary policy can also go through other channels such as labor income (e.g., Dolado, Motyovszki and Pappa (2021)).

[2]Chen and Turnovsky (2010) study the growth and inequality relation in a small open economy and find that the relation depends on agents' access to international capital markets. However, they do not study the relation between inflation and inequality, which is the focus of this paper.

[3]The main theoretical results in this paper is robust to the canonical quality-ladder growth model of aggregate technological change. The results are available upon request.

[4]See for example Brown, Martinsson and Petersen (2012), Falato and Sim (2014), Brown and Petersen (2015), and Lyandres and Palazzo (2016) for empirical evidence on the liquidity requirements of R&D investment.

inflation depends on foreign country's technology growth. When the foreign growth rate is sufficient low, the relation between inflation and income inequality is U-shaped. In contrast, income inequality monotonically increases with domestic inflation when the foreign growth rate is high enough. These predictions are supported by our empirical study and can potentially reconcile some contradictory findings in the literature. Previous empirical studies on this topic yield mixed findings, although a consensus is that at least above some threshold, income inequality increases with the inflation rate.[5] Albanesi (2007a) documents cross-country evidence that inflation and income inequality are positively correlated and proposes an explanation based on political economy. However, Galli and van der Hoeven (2001) find a U-shaped relationship in a panel of 15 OECD countries. A nonlinear relation is also documented in BulÌr (2001): inflation can significantly increase income inequality when the inflation level is very high, but not for a low level of inflation. Our model provides a framework to reconcile these previous empirical findings. We provide quantitative results from a calibrated model and cross-country empirical results to support our model predictions.

To capture income inequality, we introduce heterogeneous households in terms of asset holdings, which allows income distribution to be endogenously determined.[6] We assume that the equity market and the market for financing R&D in each country are autarky. However, a global real bond market exists such that the real interest rate is the same in both countries, which equals the weighted average of domestic and foreign technology growth. Households allocate their endowments to buy equity shares of monopolistic firms and lend to finance firms' R&D activities in the home country. To lend, households have to first hold money in the spirit of cash in advance. Households also supply labor inelastically to earn wage incomes. Given this model setup, a country's income inequality is determined by two factors: the value of financial assets (equity and bonds) relative to wage in the country and the global real interest rate.[7]

Inflation affects asset values and the global interest rate through its effect on firms' innovation activities. Incumbent firms and new entrants in each country hire labor to perform R&D (i.e., incumbent R&D and entry R&D) for innovation and the labor costs are financed by loans from domestic households. Successful innovation by a firm replaces the leading-edge technology from its current holder, adding to the number of product lines that the innovating firm is operating. In this case, incumbents' innovation intensity and the entry rate of new firms in a country jointly determine the aggregate rate of innovation, and in turn the growth rate of the country's technology and total output. In the presence of CIA constraints on R&D investment for incumbent firms and new entrants, domestic inflation raises the cost of R&D investment and reduces firms' innovation rates, leading to a negative effect on domestic technology growth. Given that the global real interest rate is the weighted average of technology growth in both countries, an increase in

[5]See Colciago, Samarina and de Haan (2019) for a survey.

[6]This setting is motivated by the empirical evidence documented in Piketty (2014).

[7]Using the British historical data, the empirical analysis of Madsen (2017) shows that asset returns are an important determinant of income inequality.

domestic inflation decreases the global real interest rate, reducing the returns of holding financial assets. We label this effect as the negative growth effect. In addition, an increase in domestic inflation affects the country's financial asset holdings in a twofold fashion. First, an increase in inflation decreases the rate of creative destruction by discouraging innovation activities, so the value of existing firms and their equity prices appreciate. Second, higher inflation increases the cost of holding money, so the demand for money to finance R&D decreases due to the CIA constraint, leading to a decline in bond holdings. Overall, the increase in equity value dominates the decrease in bond holding in our model, inducing a net increase in the value of financial assets. We label this effect as the positive valuation effect. After a threshold inflation, the positive valuation effect always dominates the negative growth effect, inducing a positive correlation between domestic inflation and inequality. However, if the negative growth effect is strong enough, the negative growth effect could dominate the positive valuation effect when inflation is low. In this case, the inflation and inequality display a U shape. When the home country has only small influence on the global real interest rate (e.g., low technology growth), the positive valuation effect always dominates the negative growth effect, leading to a monotonically increasing relation between inflation and inequality.

Although domestic inflation may improve income inequality in the growth model, we find that the effect may only be moderate, especially in an open economy. The inequality improvement is from the negative growth effect, which reduces the real interest rate. However, the effect of domestic inflation on the real interest rate is dampened in an open economy because the global real interest rate is determined by both domestic and foreign technology growth in an open economy. In addition, we show that the growth retarding effect of inflation is smaller for incumbent firms than new entrants. Although inflation increases the cost of innovation, it also increases the size of incumbent firms, which encourages more innovation activities. We show that these two effects can even cancel out, leaving no effect for inflation on incumbent firms' innovation intensity. These findings are consistent with the numerical results by calibrating our model to the US and Eurozone countries. In addition, empirical evidence based on cross-country regressions using data on 65 high income and upper middle income countries are supportive of the model-implied (U-shaped and positive) relationship between domestic inflation and domestic income inequality.

This study relates to the literature on inflation and innovation in a growth-theoretic framework that features CIA requirements. Marquis and Reffett (1994) firstly analyze the effects of inflation on innovation in the Romer (1990) type variety-expansion growth model.[8] Subsequent studies investigate the effects of inflation on innovation in the Schumpeterian type quality-ladder growth model. Representative studies include Chu and Lai (2013), Chu and Cozzi (2014), and

[8]Recently, Gil and Iglésias (2019) study the effects of inflation on innovation in a similar Romer growth model in which R&D is complemented with physical capital accumulation.

Huang, Yang and Cheng (2017).[9] Recent studies, such as Chu, Cozzi, Furukawa and Liao (2017) and Arawatari, Hori and Mino (2018), explore this issue by incorporating firm heterogeneity into R&D-based growth models.[10] However, the analysis of the above studies is based on a closed-economy setting. The study contributes to the literature by introducing an open-economy framework that is able to provide potential policy implications on cross-country interactions between inflation and inequality. One notable exception is Chu, Cozzi, Lai and Liao (2015), who also analyze the long-run effects of inflation on innovation in a two-country quality-ladder model with semi-endogenous growth. Nevertheless, all the aforementioned studies feature a representative household, the assumption of which, by nature, is unable to provide insights on inequality-related issues. The novel contribution of this study is to incorporate household heterogeneity into a two-country framework with international trade in order to analyze the effects of inflation on income inequality in addition to innovation and economic growth in a global economy.

This study is also related to the literature on innovation and inequality in an R&D-based growth model; see, for example, Zweimüller (2000), Foellmi and Zweimüller (2006), Grossman and Helpman (2018), and Aghion, Akcigit, Bergeaud, Blundell and Hemous (2019), in which the innovation-inequality relationship is their main focus. In addition, Chu and Peng (2011) and Chu and Cozzi (2018) explore the effects of R&D policy (including patents and R&D subsidies) on income inequality, whereas the present study differs from their interesting studies by considering the effects of monetary policy instead. This paper is closely related to Chu, Cozzi, Fan, Furukawa and Liao (2019a), who explore the effects of inflation on innovation and inequality. Our results complement their work in two aspects. First, the framework of Chu, Cozzi, Fan, Furukawa and Liao (2019a) considers the close-economy setting, which takes foreign economic conditions as given, and hence rules out the effect of endogenous foreign policy changes on domestic economy. Our framework, however, exploits the open-economy framework and suffices to capture the cross-country effects of inflation on income inequality. Second, the cross-country empirical evidence in Chu, Cozzi, Fan, Furukawa and Liao (2019a) suggests an inverted-U effect of inflation on income inequality, which is justified analytically by the presence of endogenous entry of heterogeneous firms. In contrast, our empirical analysis shows a U-shaped inflation-inequality relationship among countries with high global influence, and a positive relationship among countries with low global influence, both of which can be rationalized by the relative magnitude of domestic to foreign technology growth rate.

Finally, this study also contributes to a recent growing literature that unifies innovating firms and aggregate innovation in a general equilibrium framework that allows firms to add or lose

[9] Zheng, Huang and Yang (2019) and Huang, Chang and Ji (2020) explore the effects of inflation on innovation in a growth model with both variety expansion and quality improvement.

[10] Specifically, Chu, Cozzi, Furukawa and Liao (2017) consider endogenous entry of heterogeneous firms in a quality-ladder growth model, whereas Arawatari, Hori and Mino (2018) consider heterogeneous R&D abilities of firms in a variety-expansion growth model.

their product lines on the basis of innovation and creative destruction forces.[11] The pioneering works of Klette and Kortum (2004) and Lentz and Mortensen (2008) show that many behaviors under this framework are consistent with the applied micro literature (e.g., the pattern of R&D investment and its nexus to firms). Subsequent studies extends this framework to analyze various issues in applied growth theory. For example, Aghion, Akcigit, Cagé and Kerr (2016) explore the relationship between taxation and corruption. Acemoglu, Akcigit, Hanley and Kerr (2016) analyze the nature of a transition to clean technology and the use of carbon taxes. Akcigit and Kerr (2018) analyze how different types of innovation (external versus internal) affect economic growth and the firm size distribution. Acemoglu, Akcigit, Alp, Bloom and Kerr (2018) explore the implications of industrial policies on long-run growth and welfare. Akcigit, Hanley and Serrano-Velarde (2020) explore the importance of the distinctions between basic and applied research investment. This paper complements these interesting studies by focusing on monetary policy and income inequality in an open economy.

The rest of this paper proceeds as follows. Section 2 introduces the model setup. Section 3 characterizes the decentralized equilibrium. Section 4 analyzes the cross-country effects of monetary policy. Section 5 performs a quantitative exercise and an empirical analysis. Finally, Section 6 concludes this study.

2 The model

In this section, we construct an open-economy version of the monetary Schumpeterian growth model featuring both heterogeneous households and heterogeneous firms. Specifically, we extend to a two-country environment the closed-economy framework of Klette and Kortum (2004), in which quality-improving innovations give rise to growth due to the actions of entrants and incumbents, who are heterogeneous in terms of the number of product lines. Moreover, we introduce heterogeneous households in terms of asset endowment as in García-Peñalosa and Turnovsky (2006) and money demand via a CIA constraint on R&D investment as in Chu and Cozzi (2014). The nominal interest rate in each country serves as the monetary policy instrument and the effects of monetary policy are examined by considering the implications of altering the rate of nominal interest on economic growth and income inequality. When spelling out the model, to conserve space, only equations for the home country h are present, and the corresponding equations for the foreign country f are analogous.

[11] The model of firm-level innovation, including innovation by both continuing firms and new entrants, enriches the traditional endogenous technological change literature by capturing different measures of innovative performance, such as firm growth, entry, and size distribution. Therefore, this model provides a simple analytical framework that can accommodate both the dynamics of individual firms and the behavior of the aggregate economy.

2.1 Households

There is a unit measure of households in country h, and each household is indexed by $s \in [0,1]$. The infinitely-lived households are identical in terms of time preference and the lifetime utility of household s in country h is given by

$$U^h(s) = \int_0^\infty e^{-\rho t} \ln c_t^h(s) dt, \tag{1}$$

where $c_t^h(s)$ is the consumption of final goods of household s at time t, and the parameter $\rho > 0$ represents the discount rate. The asset-accumulation equation of household s expressed in real terms (i.e., denominated in units of final goods) in country h is given by

$$\dot{a}_t^h(s) + \dot{m}_t^h(s) = r_t a_t^h(s) + w_t^h - \pi_t^h m_t^h(s) + i_t^h b_t^h(s) - c_t^h(s) + \tau_t^h, \tag{2}$$

where $a_t^h(s)$ is the real value of financial assets (in the form of equity shares of monopolistic firms in country h), and r_t is the real interest rate in country h. Each household in country h inelastically provides a unit of labor to earn the real wage rate w_t^h. τ_t^h is the amount of lump-sum transfer that each household receives from the government. $m_t^h(s)$ is the real money balance held by household s that can be lent to entrepreneurs, and the amount of loans is $b_t^h(s)$. π_t^h is the inflation rate reflecting the cost of holding money, whereas i_t^h is the nominal interest rate as well as the return rate paid by entrepreneurs. Therefore, the corresponding CIA constraint facing household s is[12]

$$b_t^h(s) \leq m_t^h(s). \tag{3}$$

We follow Dinopoulos and Segerstrom (2010) to assume that there is a global financial market. In this case, the real interest rates in the two countries must be equal such that $r_t^h = r_t^f = r_t$.[13] Household s in country h maximizes her lifetime utility (1) subject to the budget constraint (2) and the CIA constraint (3). Solving this standard utility-maximization problem yields the familiar Euler equation such that

$$\frac{\dot{c}_t^h(s)}{c_t^h(s)} = r_t - \rho. \tag{4}$$

[12]In the classical CIA constraint on consumption in the conventional literature, the distribution of consumption across households is identical to that of money holdings because in equilibrium $c_t^h(s) = m_t^h(s)$, regardless of the specific fraction of consumption subject to the CIA constraint. However, as in both Italian and US data documented by Ragot (2014), the distribution of money (M1) is similar to that of financial wealth, and much more unequally distributed than that of consumption expenditure. Therefore, in addition to capturing the empirical evidence of R&D-cash flow sensitivity, the present study mainly focuses on the households' financial motives for money holding.

[13]It is useful to note that this assumption does not exclude the case of different nominal interest rates across countries. Although the nominal interest rates are different, households in the home country would not hold foreign currency. Given the same real interest rate across countries as a result of the global financial market, differences in the nominal interest rates are caused by different inflation rates. Given that the law of one price holds in our model as discussed below, the difference in inflation rates equals the percentage change in the nominal exchange rate, so a small transaction cost on foreign exchange discourages the household from holding foreign currency.

This equation implies that the growth rates of real consumption across households are identical such that $\dot{c}_t^h(s)/c_t^h(s) = \dot{c}_t^h/c_t^h$, where $c_t^h \equiv \int_0^1 c_t^h(s)ds$ is the total consumption of all households. Moreover, the no-arbitrage condition between all assets and money gives rise to the Fisher equation $i_t^h = r_t + \pi_t^h$.

2.2 Production relations

The global market produces a unique final good for consumption in the two countries. Competitive firms produce the consumption good by aggregating two types of gross outputs by country h and f (i.e., Y_t^h and Y_t^f) using a standard Cobb-Douglas aggregator as in Klenow (1996) such that[14]

$$C_t = \frac{\left(Y_t^h\right)^{1-\alpha}\left(Y_t^f\right)^{\alpha}}{(1-\alpha)^{1-\alpha}\alpha^{\alpha}}, \tag{5}$$

where $\alpha \in (0,1)$ governs the output shares of the sectoral inputs and also determines the importance of foreign goods in consumption production. Solving the profit-maximization problem yields the conditional demand functions for Y_t^h and Y_t^f, respectively, given by

$$Y_t^h = \frac{(1-\alpha)C_t}{p_{y,t}^h}, \tag{6}$$

$$Y_t^f = \frac{\alpha C_t}{p_{y,t}^f}, \tag{7}$$

where $p_{y,t}^h$ is the price of Y_t^h and $p_{y,t}^f$ is the price of Y_t^f. Both of these prices are expressed in units of the final good. Suppose that the nominal price of the final good in country h is $P_{c,t}^h$, which is denominated in units of currency in country h. Then, the assumption that the final good is freely traded across the two countries ensures the law of one price to hold such that the nominal price of the final good denominated in units of currency in country f is $P_{c,t}^f = \epsilon_t P_{c,t}^h$, where ϵ_t is the nominal exchange rate.

Gross outputs are also produced by competitive firms. In country h, competitive firms produce Y_t^h by aggregating a unit measure of intermediate goods $Z_t^h(j)$ according to the following production function:

$$\ln Y_t^h = \int_0^1 \ln Z_t^h(j)dj, \tag{8}$$

where $Z_t^h(j)$ is the quantity produced of intermediate good j. From profit maximization, the

[14]The use of a Cobb-Douglas aggregator instead of a more general CES aggregator leads to a convenience that allows for Y_t^h and Y_t^f to grow at different rates on the balanced growth path.

conditional demand function of $Z_t^h(j)$ is given by

$$Z_t^h(j) = \frac{p_{y,t}^h Y_t^h}{p_{z,t}^h(j)} = \frac{(1-\alpha)C_t}{p_{z,t}^h(j)}, \tag{9}$$

where $p_{z,t}^h(j)$ is the price (denominated in units of final good) of $Z_t^h(j)$. Moreover, the standard price index of Y_t^h is given by $p_{y,t}^h \equiv \exp\left(\int_0^1 \ln p_{z,t}^h(j)dj\right)$.

Intermediate goods in country h are not allowed to be traded, and are produced monopolistically by local innovators who hold the latest patent on product line j, according to the following production technology:

$$Z_t^h(j) = q_t^h(j) l_{z,t}^h(j), \tag{10}$$

where $q_t^h(j)$ is the product-line-specific labor productivity and $l_{z,t}^h(j)$ is the labor employed for production in country h. Then the marginal cost of production in product line j is $w_t^h/q_t^h(j)$. Each innovation improves the productivity of a given product line j from $q_t^h(j)$ to $(1+\lambda^h)q_t^h(j)$, where λ^h is the step size of quality that determines the price markup over marginal cost. Therefore, the monopolistic price is given by

$$p_{z,t}^h(j) = (1+\lambda^h)\frac{w_t^h}{q_t^h(j)}. \tag{11}$$

In addition, the profit flow and the wage expenditure are given by

$$\Pi_t^h(j) = \frac{\lambda^h}{1+\lambda^h} p_{y,t}^h Y_t^h = \frac{\lambda^h}{1+\lambda^h}(1-\alpha)C_t, \tag{12}$$

$$w_t^h l_{z,t}^h(j) = \frac{p_{y,t}^h Y_t}{1+\lambda^h} = \frac{(1-\alpha)C_t}{1+\lambda^h}. \tag{13}$$

Equations (12) and (13) indicate that the profit flow and the employment level of production labor for each product line are identical.

2.3 Innovation technology

At any given time, a firm in country h denoted by $k^h \in [0, K^h]$ is defined by a collection of product lines. In equilibrium, the number of product lines summarizes the state of a firm. We denote by n^h the number of product lines of an incumbent firm in country h. A firm expands in the product space through successful innovations, whereas it exits the economy and becomes an outsider for $n^h = 0$. With a probability of $x_{k,t}^h$, a firm is successful in its current R&D investment, it innovates over a random product line $j' \in [0,1]$. Then the productivity in line j' increases by a proportion of $(1+\lambda^h)$. In this case, the firm becomes the new monopoly producer in line j' and thereby increases the number of its production lines to $n^h + 1$. At the same time, each of its n^h current production lines is subject to the rate τ_t^h of creative destruction by new entrants and other incumbents. Therefore, in an instant of time, the number of production units of a firm increases to n^h+1 with a probability of $x^h_{k,t}$ and decreases to n^h-1 with a probability of $n^h\tau^h_t$ (both probabilities will be defined in the following subsections).

Innovations are undirected across product lines. To innovate, firms combine their existing knowledge stock that they accumulated over time (n^h) with the number of scientists ($S^h_{k,t}$) according to the following Cobb-Douglas production function:

$$X^h_{k,t}=\left(\frac{S^h_{k,t}}{\varphi^h}\right)^{\gamma^h}(n^h)^{1-\gamma^h}, \tag{14}$$

where $x^h_{k,t}$ is the Poisson innovation flow rate, $\gamma^h\in(0,1)$ is the elasticity of innovation with respect to scientists, and $\varphi^h>0$ is a scale parameter. This study follows the existing literature, such as Chu and Cozzi (2014) and Zheng, Huang and Yang (2019), to incorporate a CIA constraint on R&D investment at time t, such that households lend to the incumbent firm money, which finances the wage payment for scientists. This setting implies an extra cost of an interest payment on R&D activities based on the nominal interest rate i^h_t, which allows monetary policy to affect firms' R&D behaviors. Thus, the R&D cost function of a typical firm is given by

$$C^h(x^h_{k,t},n^h)=w^h_tS^h_{k,t}(1+\xi^hi^h_t)=\varphi^hn^hw^h_t(x^h_{k,t})^{\frac{1}{\gamma}}(1+\xi^hi^h_t), \tag{15}$$

where $x^h_{k,t}\equiv X^h_{k,t}/n^h$ is defined as the innovation intensity (probability) of the firm, and $\xi^h\in[0,1]$ is the strength of the CIA constraint on R&D in country h.

2.4 Entry

There is a mass of potential entrants into the intermediate sector. To generate one unit of arrival, entrants need to employ a level ϕ^h_t of scientists. Therefore, the production function of entrant R&D is given by

$$x^h_{e,t}=\frac{S^h_{E,t}}{\phi^h}, \tag{16}$$

where $x^h_{e,t}$ is the aggregate entry rate in the economy, $S^h_{E,t}$ is the number of scientists hired for entrant R&D. Similarly, entrants borrow money from households to facilitate their wage payments. Taking into account this borrowing cost, the free-entry condition for entry is given by

$$x^h_{e,t}V^h_t(1)=w^h_tS^h_{E,t}(1+\xi^hi_t), \tag{17}$$

which equates the value of a new entry $V^h_t(1)$ to the cost of innovation. We here assume, for analytical simplicity, that the strength of the CIA constraint on entrant R&D is identical to that on incumbent R&D.

2.5 Monetary Authority

Denote by M_t^h the nominal money supply in country h. Accordingly, the real money balance in country h is given by $m_t^h = M_t^h / P_{c,t}^h$, where $P_{c,t}^h$ is the price of consumption goods denominated in units of currency in country h. Then consider the growth rate of money supply $\dot{M}_t^h / M_t^h$ as a policy instrument that can be controlled by monetary authority in country h. In this case, the inflation rate of final goods in country h is determined by $\pi_t^h \equiv \dot{P}_{c,t}^h / P_{c,t}^h = \dot{M}_t^h / M_t^h - \dot{m}_t^h / m_t^h$. Additionally, combining this condition with the Fisher equation (i.e., $i_t^h = \pi_t^h + r_t$) yields the one-to-one relationship between the nominal interest rate and the nominal money supply, such that[15]

$$i_t^h = \dot{M}_t^h / M_t^h + \rho. \tag{18}$$

Given this result, throughout the rest of this study, we will use i_t^h to represent the instrument of monetary policy in country h for simplicity. Finally, monetary authority in country h redistributes to domestic households seigniorage revenues in the form of a lump-sum transfer, namely $\tau_t^h = \dot{M}_t^h / P_{c,t}^h = \left(\dot{M}_t^h / M_t^h\right)\left(M_t^h / P_{c,t}^h\right) = \left(\dot{m}_t^h / m_t^h + \pi_t^h\right) m_t^h = \dot{m}_t^h + \pi_t^h m_t^h$.

3 Monetary policy and economic growth

This section solves steady-state equilibrium of the model and explores the effects of monetary policy on economic growth. To solve the model, we focus on a balanced growth path (BGP), where all aggregate variables grow at a constant rate, and the firm size distribution is invariant. Hence, along BGP, time subscript t is dropped when it causes no confusion.

3.1 Stationary equilibrium

We first analyze the innovation decision of firms. The stock-market value of an n-product firm $V_t^h(n^h)$ at time t satisfies the following Bellman equation:

$$rV_t^h(n^h) - \dot{V}_t^h(n^h) = \max_{x_k^h \geq 0} \left\{ \begin{array}{l} n^h \Pi_t^h - n^h w_t^h \varphi^h x_k^{\frac{1}{\gamma^h}} (1 + \xi^h i^h) \\ + n^h x_k^h [V_t^h(n^h + 1) - V_t^h(n^h)] \\ + n^h \tau^h [V_t^h(n^h - 1) - V_t^h(n^h)] \end{array} \right\},$$

where $\tau^h = x_k^h + x_e^h$ is the aggregate rate of creative destruction. This equation is similar to the ones in Klette and Kortum (2004) and Aghion, Akcigit and Howitt (2014), except the presence of $(1 + \xi^h i^h)$, which captures the additional effect of the CIA constraint. It is easy to verify that the value function takes the form of

$$V_t^h(n^h) = n^h v^h C_t, \tag{19}$$

[15] On the balanced growth path, c_t^h and m_t^h grow at the same rate of $r_t - \rho$ according to the Euler equation.

where v^h is the average normalized value of a production unit in country h. Solving the maximization problem yields

$$x_k^h = \left[\frac{\gamma^h v^h}{\varphi^h \omega^h (1+\xi^h i^h)}\right]^{\frac{\gamma^h}{1-\gamma^h}}, \tag{20}$$

where $\omega^h = w_t^h / C_t$. Substituting (19) into (17), coupled with (16), yields

$$v^h = \phi^h \omega^h (1+\xi^h i^h). \tag{21}$$

Combining (20) and (21) shows that the (steady-state) equilibrium of an incumbent's innovation intensity is given by

$$x_k^h = \left(\frac{\gamma^h \phi^h}{\varphi^h}\right)^{\frac{\gamma^h}{1-\gamma^h}}, \tag{22}$$

and substituting (19) into the Bellman equation yields the equilibrium entry rate such that

$$x_e^h = \frac{(1-\alpha)\lambda^h}{\phi^h \omega^h (1+\lambda^h)(1+\xi^h i^h)} - \gamma^h \left(\frac{\gamma^h \phi^h}{\varphi^h}\right)^{\frac{\gamma^h}{1-\gamma^h}} - \rho, \tag{23}$$

where the Euler equation $g = r - \rho$ has been applied and the steady-state value of ω^h will be given by (28).

To characterize the equilibrium, we first derive the firm size distribution in country h. For any given incumbent firm with n^h product lines, it will gain new products at the rate of $n^h x_k^h$ and lose existing products at the rate of $n^h \tau^h = n^h(x_k^h + x_e^h)$. Hence, in expectation each incumbent firm is shrinking at the rate given by

$$\frac{n^h x_k^h - n^h \tau^h}{n^h} = -x_e^h.$$

Denote μ_{n^h} the mass of firms with n^h leading-edge product lines in country h. Thus, the distribution must satisfy the flow equations that equate the inflows and the outflows such that

$$\begin{aligned}
&\mu_1^h \tau^h = x_e^h \qquad \text{for} \quad \text{entry and exit,} \\
&(x_k^h + \tau^h)\mu_1^h = 2\mu_2^h \tau^h + x_e^h \qquad \text{for} \quad n^h = 1, \\
&(n^h - 1)x_k^h \mu_{n^h-1} + (n^h+1)\tau^h \mu_{n^h+1} = (x_k^h + \tau^h) n^h \mu_{n^h}, \qquad \text{for} \quad n^h > 1.
\end{aligned}$$

Moreover, because there is a unit mass of products and each product is produced by one firm, we then have

$$\sum_{n^h=1}^{\infty} n^h \mu_{n^h} = 1. \tag{24}$$

We are now in position to define the balanced growth path equilibrium. Define by S_K^h and

S_K^f the aggregate level of incumbent R&D labor in country h and f, respectively. Thus we have $S_K^h = \sum_{n^h=1}^{\infty} \mu_{n^h} S_k^h$ and $S_K^f = \sum_{n^f=1}^{\infty} \mu_{n^f} S_k^f$. In addition, denote the aggregate level of production labor, asset holdings, and bond holdings in country h by $L_{Z,t}^h \equiv \int_0^1 l_{z,t}^h(j)dj$, $a_t^h \equiv \int_0^1 a_t^h(s)ds$, and $b_t^h \equiv \int_0^1 b_t^h(s)ds$, respectively. Similarly, the counterparts in country f are denoted by $L_{Z,t}^f \equiv \int_0^1 l_{z,t}^f(j)dj$, $a_t^f \equiv \int_0^1 a_t^f(s)ds$, and $b_t^f \equiv \int_0^1 b_t^f(s)ds$.

Definition 1. *The balanced growth path equilibrium consists of a sequence of prices* $\{P_{c,t}^h, P_{c,t}^f, p_{y,t}^h, p_{y,t}^f, p_{z,t}^h, p_{z,t}^f, w_t^h, r_t, i_t^h, i_t^f, V_t^h(n), V_t^f(n), \epsilon_t\}_{t=0}^{\infty}$, *and a couple of allocations* $\{C_t, c_t^h, c_t^f, m_t^h, m_t^f, b_t^h, b_t^f, Y_t^h, Y_t^f, Z_t^h(j), Z_t^f(j), L_{Z,t}^h, S_{K,t}^h, S_{E,t}^h, L_{Z,t}^f, S_{K,t}^f, S_{E,t}^f\}_{t=0}^{\infty}$ *such that all households maximize utility, all firms maximize profits, and all markets clear. That is, (i) the global final-good market clears such that* $C_t = c_t^h + c_t^f$; *(ii) the labor-market-clearing conditions in country h and f are given by* $L_{Z,t}^h + S_{K,t}^h + S_{E,t}^h = 1$, *and* $L_{Z,t}^f + S_{K,t}^f + S_{E,t}^f = 1$, *respectively; (iii) the asset markets in country h and f clear such that* $\sum_{n^h=1}^{\infty} \mu_{n^h} V_t^h(n^h) = a_t^h$ *and* $\sum_{n^f=1}^{\infty} \mu_{n^f} V_t^f(n^f) = a_t^f$; *(iv) the bond markets in country h and f clear such that* $b_t^h = \xi^h w_t^h(S_{K,t}^h + S_{E,t}^h)$ *and* $b_t^f = \xi^f w_t^f(S_{K,t}^f + S_{E,t}^f)$, *respectively.*

Integrating (13) over j and rearranging the resulting equation yield the aggregate production labor in country h on the BGP such that

$$L_Z^h = \frac{1-\alpha}{(1+\lambda^h)\omega^h} \tag{25}$$

The number of scientists devoted to entrant R&D in country h is derived by using (16):

$$S_E^h = \phi^h x_e^h, \tag{26}$$

where x_e^h is given by (23). Using $S_k^h = n^h \varphi^h (x_k^h)^{1/\gamma^h}$ and x_k^h in (22) yields

$$S_K^h = \sum_{n^h=1}^{\infty} \mu_{n^h} S_k^h = \varphi^h \left(\frac{\gamma^h \phi^h}{\varphi^h} \right)^{\frac{1}{1-\gamma^h}}. \tag{27}$$

where the second equality applies (24). Substituting (25), (26) and (27) into the labor-market-clearing condition in country h yields

$$\omega^h = \frac{(1-\alpha)(1+\lambda^h+\xi^h i^h)}{(1+\lambda^h)(1+\xi^h i^h)(1+\phi^h \rho)}. \tag{28}$$

Substituting (28) into (23) yields the steady-state value of entry rate such that

$$x_e^h = \frac{\lambda^h(1+\phi^h\rho)}{\phi^h(1+\lambda^h+\xi^h i^h)} - \gamma^h \left(\frac{\gamma^h \phi^h}{\varphi^h} \right)^{\frac{\gamma^h}{1-\gamma^h}} - \rho. \tag{29}$$

Accordingly, we obtain the following result.

Lemma 1. *In country h, the entry rate is decreasing in the nominal interest rate and the incumbent's innovation intensity is independent of it.*

Proof. Use (29) to show that x_e^h is decreasing in i^h and (22) to show that x_k^h is invariant of i^h. $\square$

Intuitively, a higher nominal interest rate i^h raises the cost of entrant R&D and decreases the incentives for new product lines, so the entry rate x_e^h declines. Nevertheless, a change in the nominal interest rate yields two effects on the incumbent's innovation intensity. On the one hand, a higher nominal interest rate raises the R&D cost of incumbents and decreases their incentives for innovation. On the other hand, a higher nominal interest rate reduces the rate of creative destruction caused by potential entry, which leads to a larger firm size for each incumbent and an increase in the incentives for incumbents' innovation. These two contrasting effects offset one another, giving rise to x_k^h being independent of i^h.

3.2 Inflation and growth

Substituting (10) into (8) yields the production function of gross output in country h such that

$$\ln Y_t^h = \int_0^1 \ln Z_t^h(j)dj = \ln\left[\frac{1-\alpha}{(1+\lambda^h)\omega^h}\right] + \int_0^1 \ln q_t^h(j)dj, \tag{30}$$

where the second equality applies (13). Define by $Q_t^h \equiv \exp\left(\int_0^1 \ln q_t^h(j)dj\right)$ the aggregate quality index in country h. During a small time interval Δt, the quality index evolves as follows:

$$\begin{aligned}\ln Q_{t+\Delta t}^h &= \int_0^1 \left\{\tau^h \Delta t \ln[(1+\lambda^h)q_t^h(j)] + (1-\tau^h\Delta t)\ln q_t^h(j)\right\} dj + o(\Delta t)\\ &= \tau^h \Delta t \ln(1+\lambda^h) + \ln Q_t^h + o(\Delta t),\end{aligned}$$

which implies that the growth rate of quality index in country h is given by

$$\begin{aligned}g^h \equiv \frac{\dot{Q}_t^h}{Q_t^h} = \frac{\dot{Y}_t^h}{Y_t^h} &= (x_e^h + x_k^h)\ln(1+\lambda^h)\\ &= \left[\frac{\lambda^h(1+\phi^h\rho)}{\phi^h(1+\lambda^h+\xi^h i^h)} + (1-\gamma^h)\left(\frac{\gamma^h\phi^h}{\varphi^h}\right)^{\frac{\gamma^h}{1-\gamma^h}} - \rho\right]\ln(1+\lambda^h).\end{aligned} \tag{31}$$

Apparently, the technology growth rate g^h in country h is decreasing in the domestic nominal interest rate i^h, whereas it is independent of the foreign nominal interest rate i^f.

Following the same logic, one can also derive the analogous equations for $\{Y_t^f, Q_t^f\}$ and the growth rate of quality index in country f such that

$$g^f \equiv \frac{\dot{Q}_t^f}{Q_t^f} = \frac{\dot{Y}_t^f}{Y_t^f} = (x_e^f + x_k^f)\ln(1+\lambda^f)$$
$$= \left[\frac{\lambda^f(1+\phi^f\rho)}{\phi^f(1+\lambda^f+\xi^f i^f)} + (1-\gamma^f)\left(\frac{\gamma^f\phi^f}{\varphi^f}\right)^{\frac{\gamma^f}{1-\gamma^f}} - \rho\right]\ln(1+\lambda^f), \tag{32}$$

which is decreasing in the country f's nominal interest rate i^f and independent of the country h's nominal interest rate i^h.

Given (31) and (32), differentiating the log of (5) with respect to time yields the steady-state growth rate of output such that $g \equiv (1-\alpha)g^h + \alpha g^f$. Then differentiating g with respect to i^h and i^f, respectively, yields

$$\frac{\partial g}{\partial i^h} = (1-\alpha)\underbrace{\frac{\partial g^h}{\partial i^h}}_{<0} + \alpha\underbrace{\frac{\partial g^f}{\partial i^h}}_{=0}; \qquad \frac{\partial g}{\partial i^f} = (1-\alpha)\underbrace{\frac{\partial g^h}{\partial i^f}}_{=0} + \alpha\underbrace{\frac{\partial g^f}{\partial i^f}}_{<0}. \tag{33}$$

The above results are summarized in the following proposition.

Proposition 1. *The growth rate of domestic (foreign) technology is decreasing in the domestic (foreign) nominal interest rate but independent of the foreign (domestic) nominal interest rate. The economic growth rate in a country is decreasing in both the domestic and foreign nominal interest rates.*

Proof. Proven in the text. □

4 Monetary policy and inequality

In this section, we explore how domestic income inequality is affected by the domestic monetary policy and the foreign counterpart, respectively. To do so, we first show in Section 4.1 that the wealth distribution is stationary and exogenously determined by its initial distribution. Thereafter, we explore the cross-country effects of monetary policy on income distribution in Section 4.2.

4.1 Wealth distribution

Suppose that at time 0, the consumption share of household s in country h is $\theta_{c,0}^h(s) \equiv c_0^h(s)/c_0^h$, and the general distribution function for the consumption share features a mean of one and a standard deviation of $\sigma_c^h > 0$. According to the Euler equation (4), the motion of households' consumption share in country h is time-invariant such that at any point of time t, it is given by

$$\frac{\dot{\theta}^h_{c,t}(s)}{\theta^h_{c,t}(s)} = \frac{\dot{c}^h_t(s)}{c^h_t(s)} - \frac{\dot{c}^h_t}{c^h_t} = 0. \tag{34}$$

Therefore, the consumption share of household s in country h equals to its initial value for all $t > 0$, namely, $\theta^h_{c,t}(s) = \theta^h_{c,0}(s)$. However, $\theta^h_{c,0}(s)$ is an endogenous variable that can be affected by economic policies, and is a function of the initial wealth share of household s. To see this, we now characterize the distribution of household s' wealth share. Since household s at any time exhausts all her cash such that $b^h_t(s) = m^h_t(s)$ in equilibrium, households' asset-accumulation function in (2) can be rewritten as

$$\dot{a}^h_t(s) + \dot{b}^h_t(s) = r_t[a^h_t(s) + b^h_t(s)] + w^h_t + \tau^h_t - c^h_t(s), \tag{35}$$

where the Fisher equation $i^h_t = r_t + \pi^h_t$ is applied. Aggregating (35) for all s yields

$$\dot{a}^h_t + \dot{b}^h_t = r_t(a^h_t + b^h_t) + w^h_t + \tau^h_t - c^h_t. \tag{36}$$

Define $d^h_t(s) \equiv a^h_t(s) + b^h_t(s)$ as household s' wealth at time t, which consists of financial assets and bond holdings. Moreover, we define $\theta^h_{d,0}(s) \equiv d^h_0(s)/d^h_0$ as the initial share of wealth of household s in country h, which is exogenously given by at time 0. The general distribution function for households' wealth share features a mean of one and a standard deviation of $\sigma^h_d > 0$. It is useful to note that the definition $d^h_t(s)$ relates the distribution of money to financial wealth; the deviation of the money distribution is identical to that of financial wealth distribution. This feature allows us to mimic the fact documented by Ragot (2014).[16]

Using (35) and (36) to derive the motion of household s' wealth share $\theta^h_{d,t}(s) \equiv d^h_t(s)/d_t(s)$ in country h for all t yields

$$\frac{\dot{\theta}^h_{d,t}(s)}{\theta^h_{d,t}(s)} = \frac{\dot{d}^h_t(s)}{d^h_t(s)} - \frac{\dot{a}^h_t}{a^h_t} = \frac{c^h_t - w^h_t - \tau^h_t}{d^h_t} - \frac{c^h_t(s) - w^h_t - \tau^h_t}{d^h_t(s)},, \tag{37}$$

which can be reexpressed as

$$\dot{\theta}^h_{d,t}(s) = \underbrace{\frac{c^h_t - w^h_t - \tau^h_t}{d^h_t}}_{\chi_1=\rho} \theta^h_{d,t}(s) - \frac{c^h_t \theta^h_{c,0}(s) - w^h_t - \tau^h_t}{d^h_t}, \tag{38}$$

where $\chi_1 = \rho > 0$ is obtained by using (36) and the fact that $\{a^h_t, b^h_t, c^h_t, w^h_t, \tau^h_t\}$ all grow at the same steady-state rate of g along the BGP. Since $\theta^h_{d,t}(s)$ is a state variable and the coefficient on $\theta^h_{d,t}(s)$ is positive, the only solution for the one-dimensional differential equation that describes

[16] Ragot (2014) uses the US data to show that in 2004, the Gini coefficient is around 0.8 for the distribution of net wealth and the counterpart is also 0.8 for that of money.

the potential evolution of $\theta^h_{d,t}(s)$ given an initial $\theta^h_{d,0}(s)$, represented in (38), is $\dot{\theta}^h_{d,t}(s) = 0$ for all $t > 0$. This can be achieved by having the consumption share $\theta^h_{c,t}(s)$ jump to its steady-state value $\theta^h_{c,0}(s)$, which is shown in Appendix A.1. The following proposition summarizes the result.

Lemma 2. *Hold constant the nominal interest rates i^h and i^f, the wealth share of household s is stationary over time and exogenously determined at time 0 such that $\theta^h_{d,t}(s) = \theta^h_{d,0}(s)$ for all t.*

Proof. See Appendix A.1. □

4.2 Income distribution

From (35), the before-transfer income earned household s in country h is $I^h_t(s) = rd^h_t(s) + w^h_t$. Aggregating it for all s yields the total income earned by households in country h given by $I^h_t = rd^h_t + w^h_t$. Combining both equations yields the share of income earned by household s given by

$$\theta^h_{I,t}(s) \equiv \frac{I^h_t(s)}{I^h_t} = \frac{\theta^h_{d,t}(s) rd^h_t + w^h_t}{rd^h_t + w^h_t}, \tag{39}$$

where the second equality applies $d^h_t(s) = \theta^h_{d,t}(s) d^h_t$ from Lemma 2. The distribution function of income share $\theta^h_{I,t}(s)$ has a mean of one and the following standard deviation such that

$$\sigma^h_I(t) = \sqrt{\int_0^1 [\theta^h_{I,t}(s) - 1]^2 ds} = \frac{rd^h_t/w^h_t}{1 + rd^h_t/w^h_t} \sqrt{\int_0^1 [\theta^h_{d,t}(s) - 1]^2 ds} = \frac{rd^h_t/w^h_t}{1 + rd^h_t/w^h_t} \sigma^h_d. \tag{40}$$

Given an exogenously determined value of σ^h_d, (40) implies that the degree of income inequality is an increasing function of rd^h_t/w^h_t because an unequal distribution of wealth is the source of income inequality in this model.

Recall that the total wealth in country h is given by $d^h_t = a^h_t + b^h_t$. From the asset-market-clearing condition, we can obtain the asset-wage ratio given by

$$\frac{a^h_t}{w^h_t} = \frac{\sum_{n=1}^{\infty} \mu^h_n V^h_t(n)}{w^h_t} = \frac{v^h}{\omega^h} = \phi^h (1 + \xi^h i^h), \tag{41}$$

where the second and last equalities apply (24) and (21). Obviously, a^h_t/w^h_t is increasing in the domestic nominal interest rate i^h and independent of the foreign nominal interest rate i^f. In addition, substituting (27) and (26) into b^h_t/w^h_t yields the bond-wage ratio given by

$$\frac{b^h_t}{w^h_t} = \frac{\xi^h \lambda^h (1 + \phi^h \rho)}{1 + \lambda^h + \xi^h i^h} - \xi^h \phi^h \rho, \tag{42}$$

which is increasing in the domestic nominal interest rate i^h and independent of the foreign nominal interest ratei^f. Thus, we can derive the ratio of total interest income to wage income given by

$$\frac{rd_t^h}{w_t^h} = \frac{r(a_t^h + b_t^h)}{w_t^h} = (\rho + g)\left\{\phi^h(1+\xi^h i^h) + \frac{\xi^h \lambda^h (1+\phi^h \rho)}{1+\lambda^h+\xi^h i^h} - \xi^h \phi^h \rho\right\}. \tag{43}$$

Differentiating (43) with respect to i^f shows that a rise in the foreign nominal interest rate decreases the ratio of total interest income to wage income rd_t^h/w_t^h via the growth-retarding effect according to Proposition 1, given that it does not affect the ratio of d_t^h/w_t^h in country h. Thus, using equation (40), it is known that a higher i^f reduces income inequality in country h.

As for the effect of the domestic nominal interest rate i^h on the ratio of total interest income to wage income rd_t^h/w_t^h, it operates through affecting both the ratio of d_t^h/w_t^h and the economic growth rate g (as well as the real interest rate r). As for the former channel, there are two opposing effects. First, a higher i^h raises the expected innovative firm value per product line v^h, because a larger firm value must be accompanied with the rise in R&D costs given the free entry to the R&D sector. This corresponds to the *asset-value* effect as identified in Chu and Cozzi (2018). As a result, a_t^h/w_t^h rises, which tends to increase d_t^h/w_t^h. Second, a higher in i^h depresses the money demand for R&D because the cost of money required for facilitating the wage payment is larger. For this reason, b_t^h/w_t^h decreases in response, which tends to decrease d_t^h/w_t^h. In total, the positive effect of increasing i^h on a_t^h/w_t^h always dominates the negative effect on b_t^h/w_t^h when i^h is at its high level, but may be dominated by the negative effect when i^h is at a lower level, thereby leading to a monotonically increasing or (potentially) U-shaped effect on d_t^h/w_t^h.

In addition, a rise in i^h tends to lower the ratio of interest income to wage income rd_t^h/w_t^h by reducing the domestic economic growth rate g from Proposition 1 and then the real interest rate r. This corresponds to the *interest-rate* effect as identified in Chu and Cozzi (2018). Nevertheless, the main difference arising in this study is that the effect of i^h on the domestic income inequality through r is contingent on g, which in turn is partly determined by the foreign technology growth rate g^f. More specifically, if the foreign technology growth rate g^f is relatively low, the relationship between the domestic nominal interest rate and domestic income inequality becomes U-shaped: that is, the negative effect through r tends to play a dominant role for low initial levels of domestic nominal interest rate i^h, whereas the positive effect through d_t^h/w_t^h tends to play a dominant role for higher levels of the domestic nominal interest rate i^h. Accordingly, there exists a positive rate of domestic nominal interest that minimizes domestic income inequality. The intuition of this result is that in the case of a low foreign technology growth rate g^f, the contribution of the domestic technology growth rate g^f to the domestic growth rate g^h becomes more significant, which tends to strengthen the *interest-rate effect* that is determined by the domestic interest rate i^h, especially when i^h is low.

In contrast, if the foreign technology growth rate g^f is relatively high, then under a rise in i^h, the effect through d_t^h/w_t^h always dominates the effect through r, leading to a higher degree of income inequality. Therefore, the domestic nominal interest rate that minimizes domestic income inequality is zero. Intuitively, in the case of a high foreign technology growth rate g^f, the contribution of the domestic technology growth rate g^f to the domestic growth rate g^h becomes less significant, which tends to drastically weaken the *interest-rate effect* for all levels of the domestic interest rate i^h.

Proposition 2. *For a sufficiently low (high) foreign technology growth rate, the effect of domestic inflation rate on domestic income inequality is U-shaped (monotonically increasing). Moreover, domestic income inequality is monotonically decreasing in the foreign inflation rate.*

Proof. See Appendix A.2. □

Notice that Proposition 2 implies that the effect of domestic inflation on domestic income inequality is closely related to the size of a country (i.e., the value of α). Specifically, for small open economies (SOEs), namely under a large α, the inflation of each country is positively correlated with its income inequality. In contrast, for large open economies (LOEs), namely under a small α, the relationship between inflation and income inequality displays a U shape. Intuitively, recall that domestic inflation is jointly determined by the real interest rate r and the ratio of asset and bond values to wage d_t^h/w_t^h. In this setting, the ratio d_t^h/w_t^h is only affected by home factors and it always increases with domestic inflation. However, the real interest rate r can be affected by both home and foreign inflation, since r is given by a weighted average of domestic and foreign technology growth (i.e., $r = g + \rho = (1-\alpha)g^h + \alpha g^f + \rho$). Given the weight of each country, r will be dominated by the country whose technology growth rate is higher. If the domestic country is an LOE, r will mainly reflect the domestic country's technology growth; this is more likely to occur when the foreign country exhibits a low growth rate of technology.[17] In contrast, if the domestic country is an SOE, it barely has no impact on r, since SOEs have no influence on the global interest rate by assumption. Therefore, r will mainly reflect the foreign country's technology growth; this is more likely to occur when the foreign country exhibits a high growth rate of technology. Accordingly, the relationship between domestic inflation and domestic income inequality is increasing as determined by the ratio d_t^h/w_t^h. In Section 5, both the numerical analysis and empirical analysis will show that a country's size is important for how domestic inflation affects domestic income inequality.[18]

5 Quantitative analysis

In this section, we calibrate the model to the US and Eurozone data to perform a quantitative analysis. Without loss of generality, we assume that US is the domestic country, whereas

[17] To see this, consider an extreme case of the foreign country having zero technology growth. In this case, r is completely determined by domestic technology growth and the relationship between domestic inflation and domestic income inequality becomes U-shaped; the domestic country is actually equivalent to a close economy.

[18] In Subsection 5.4, small open economies (SOEs) and large open economies (LOEs) are denoted by low influence economies (LIEs) and high influence economies (HIEs), respectively.

Eurozone is the foreign country. In particular, we numerically evaluate the relationship between inflation rates and five targeted macroeconomic variables, namely technology growth rates, R&D intensity, income inequality, entry rates, and the distribution of market shares possessed by firms of different sizes, based on a benchmark of parameter values, along with several alternatives that are exploited for sensitivity analysis and policy experiments.

5.1 Calibration

A thorough numerical analysis requires us to assign reasonable values to the following set of structural parameters $\{\rho, \alpha, \lambda^h, \lambda^f, \phi^h, \phi^f, \varphi^h, \varphi^f, \xi^h, \xi^f, \gamma^h, \gamma^f\}$. We set the discount rate ρ to a standard value of 0.05. The parameters λ^h and λ^f for the step size of quality improvement in domestic and foreign countries are both chosen to be 0.05, which is consistent with the range of estimates from Akcigit and Kerr (2018). Following Chu, Cozzi, Lai and Liao (2015), we calibrate the two parameters regulating the strength of CIA constraints, namely ξ^h and ξ^f, to 0.33 and 0.56, respectively, and the parameter regulating the importance of foreign output to domestic consumption α to 0.42. Following Aghion, Akcigit, Cagé and Kerr (2016), we calibrate γ^h and γ^f to 0.5, and set the entry rate in the US x_e^h to 0.058. As for the entry rate of Eurozone countries, we follow Lentz and Mortensen (2008), which exploit the data on Denmark to estimate the firm entry rate, to set x_e^f to 0.04. In addition, the growth rates of the US and Eurozone economies are set to 2%, and inflation rates are calibrated to 2.7% and 2.1%, respectively. Matching the calibrated long-run economic growth rates and firm entry rates, conditional upon the aforementioned parameter values, suffices to pin down the productivity parameters ϕ^h, ϕ^f, φ^h and φ^f. Consequently, the implied US and Eurozone innovation rates, τ^h and τ^f, are around 0.41, which is close to the estimate in the literature (i.e. Acemoglu and Akcigit (2012)), highlighting that the time length of new arrival of innovation is approximately 3 years. Values of parameters and targeted moments are summarized in Table 1.

Table 1: Parameter values in baseline calibration

Targeted moments					
g^h	g^f	π^h	π^f	x_e^h	x_e^f
2.0%	2.0%	2.7%	2.1%	5.8%	4.0%
Exogenously determined parameters					
ρ	α	ξ^h	ξ^f	λ^h	λ^f
0.05	0.42	0.33	0.56	0.05	0.05
Internally calibrated parameters					
	ϕ^h	ϕ^f	φ^h	φ^f	
	0.1641	0.1665	0.2331	0.2551	

5.2 Effects of inflation: benchmark

In the quantitative practice, first, we use the parameter values reported in Table 1 as a benchmark, and explore the effects of domestic inflation on the five targeted variables in both domestic and foreign countries. Fixing the foreign inflation rate at 2.1%, we allow the domestic inflation rate to vary between -20% and 20%. Panels (a) and (b) of Figure 1 suggests that the domestic technology growth rate is decreasing in domestic inflation, partly because higher domestic inflation reduces domestic R&D intensity, and hence, generates a sizable growth-regarding effect. Consistent with the model prediction, however, R&D intensity and the technology growth rate abroad are unaffected by domestic inflation. As for the coefficient rd_t/w_t governing the dispersion of households' income, Figure 1 – Panel (c) suggests that domestic income inequality is monotonically increasing in domestic inflation. It is found that income inequality rises by 1.59% (from 0.0126 to 0.0128) when the inflation rate increases from 2% to 9%. To the contrary, higher domestic inflation unambiguously mitigates foreign income inequality. Therefore, evidence under the benchmark scenario indicates that the maximum domestic technology growth rate and the minimum domestic income inequality can be achieved simultaneously when the central bank sets the long-run domestic inflation target at the lowest possible value.

As shown in Figure 1 – Panel (d), a second source of growth-retarding effect originates from a lower entry rate induced by higher inflation. Given that the innovation rate by incumbent is constant, higher inflation reduces the aggregate innovation rate, leading to slower technological progress. In addition, Figure 1 – Panel (e) shows that higher inflation reduces the number of firms with very few product lines in a noticeable manner, whereas its impact on the number of firms with a larger amount of product lines seems little to nonexistent.

Figure 2 reports the effects of foreign inflation, whose value in consideration also ranges from -20% to 20%. Once we view the foreign country as the domestic country, the interpretation of the qualitative pattern of Figure 2 remains similar to that of Figure 1, which is attributed to the calibrated parameters capturing the fact that the US and Eurozone economies are largely symmetric. However, it is worth noting that, under the benchmark scenario where the difference between domestic and foreign technological growth rates is not sufficiently large, the model does not generate a U-shaped relationship between inflation and income inequality in the domestic country. Further numerical exploration of Proposition 2 is discussed in the next subsection.

5.3 Sensitivity analysis and policy experiment

To perform sensitivity analysis, we restrict our attention to the effects of domestic inflation, and consider alternative values of the structural parameters $\{\xi^h, \xi^f, \alpha, \phi^h, \phi^f\}$. First, when we enlarge the difference between ξ^h and ξ^f by setting $\xi^h = 0.2$ and $\xi^f = 0.8$, the qualitative pattern of the main model implications stays unchanged. As shown in Figure 3 – Panel (c), the relationship between domestic inflation and domestic income inequality is still positive, even

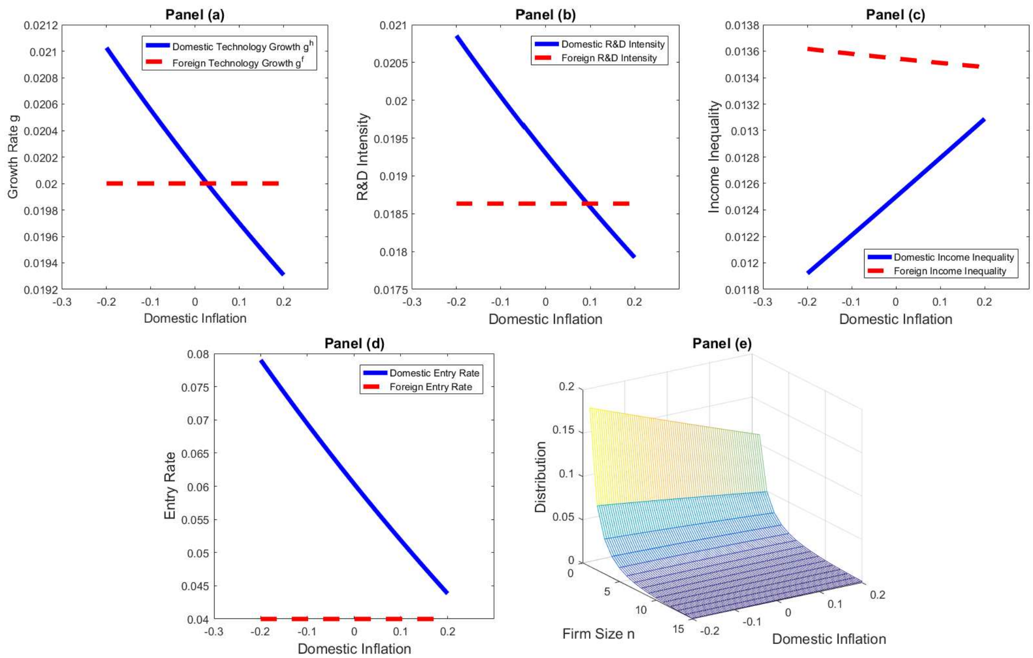

Figure 1: Effects of Domestic Inflation.

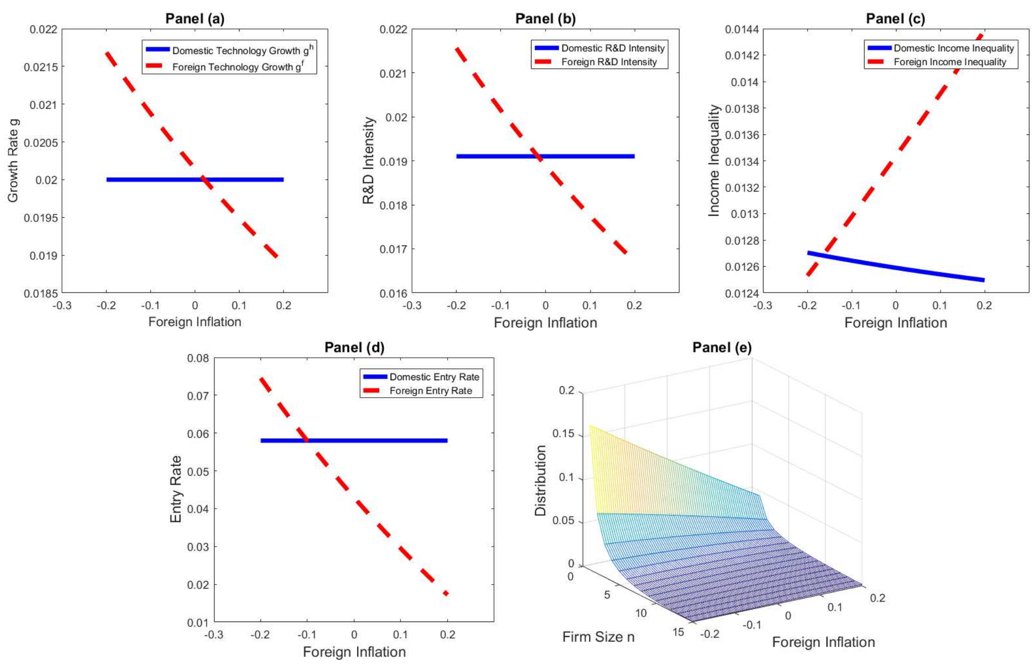

Figure 2: Effects of Foreign Inflation.

though domestic income inequality is now consistently and substantially lower than foreign income inequality. In addition, in the presence of a relatively slack CIA constraint, domestic inflation yields a quantitatively small impact on the firm distribution. Once we tighten the CIA constraint faced by domestic firms by setting $\xi^h = \xi^f = 0.5$, as reported in Figure 4, the effect of inflation on the number of firms with fewer product lines becomes sizable, and domestic income inequality is no longer consistently lower than foreign income inequality. It is found that domestic income inequality exceeds its foreign counterpart when domestic inflation rate is above 7%. As shown in Figure 5, the model implications are also robust to the calibration where the importance of Eurozone output in US economy, α, is reduced to 0.25.

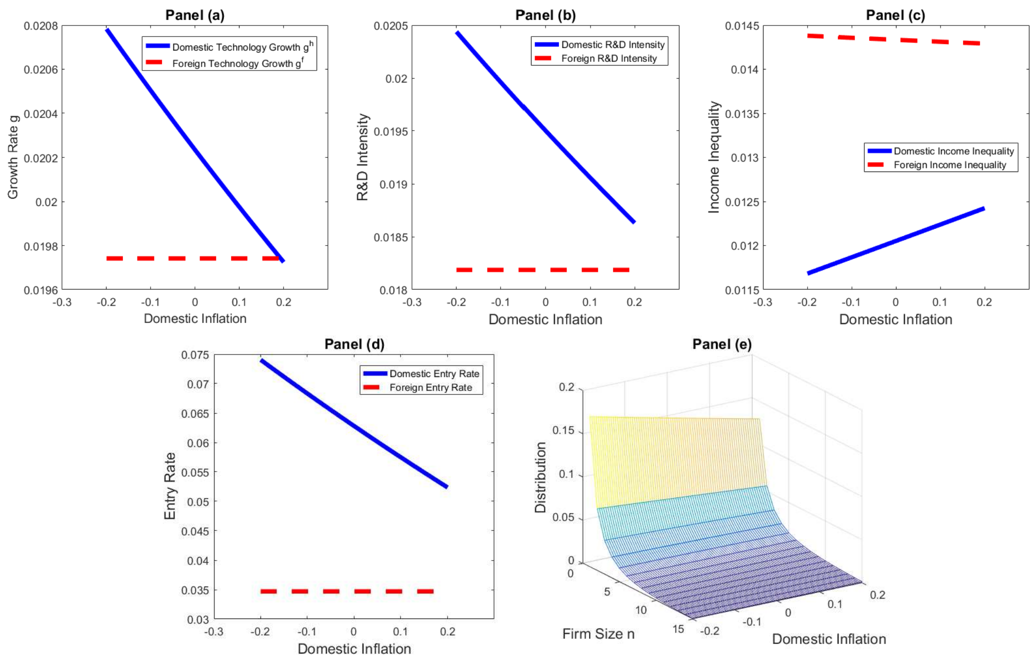

Figure 3: Effects of Domestic Inflation ($\xi^h = 0.2, \xi^f = 0.8$).

In Section 4, Proposition 2 suggests that a U-shaped relationship between domestic inflation and domestic income inequality occurs when foreign technology growth rate is sufficiently low. To further explore the model implication, we consider the following set of parameters. Keeping $\alpha = 0.25$ and $\xi^h = \xi^f = 0.5$, we increase the step size of domestic quality improvement λ^h to 0.085, while reducing the step size of foreign innovation by 0.005 (from 0.05 to 0.045). In addition, we set the productivity parameter $\phi^h = 0.085$ to further raise domestic productivity growth. Our intention is to generate a sizable gap between domestic and foreign technology growth rate, and in the meantime, ensure a positive foreign firm entry rate. Under this set of calibrated parameters, which is referred to as the U-shaped calibration hereafter, Figure 6 shows that the effect of domestic inflation on domestic income inequality becomes U-shaped, whereas foreign income inequality is still monotonically decreasing in domestic inflation. It is found that the inequality-minimizing inflation rate is around 1%, which is lower than that in the quantitative analysis of Menna and Tirelli (2017). Under the U-shaped calibration, domestic country exhibits remarkably higher values of R&D intensity, entry rate and productivity growth than those in the

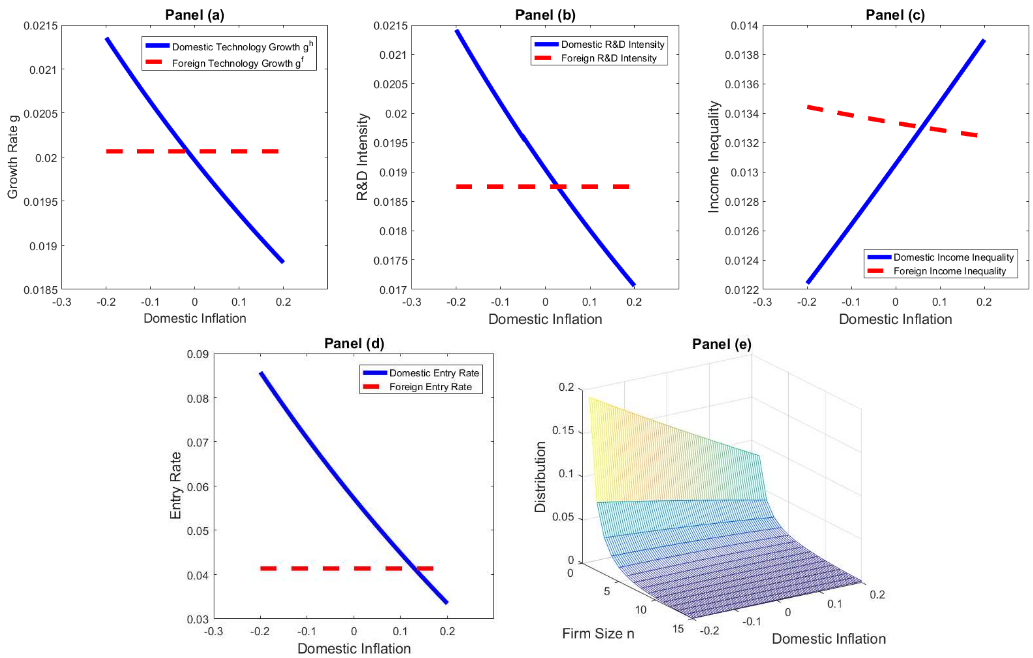

Figure 4: Effects of Domestic Inflation ($\xi^h = \xi^f = 0.5$).

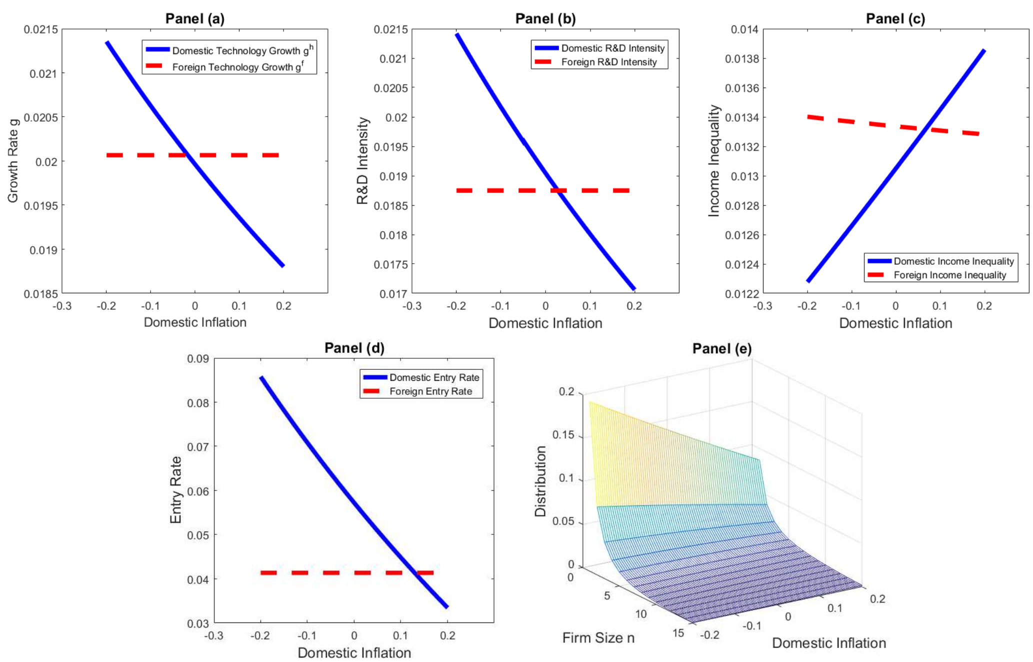

Figure 5: Effects of Domestic Inflation ($\alpha = 0.25; \xi^h = \xi^f = 0.5$).

foreign country. Domestic firm distribution, however, seems largely unaffected by inflation rate.

In an alternative practice, we maintain the U-shaped calibration, but increase α to 0.6. It is worth noting that a large α indicates that the domestic country is a small open economy rather

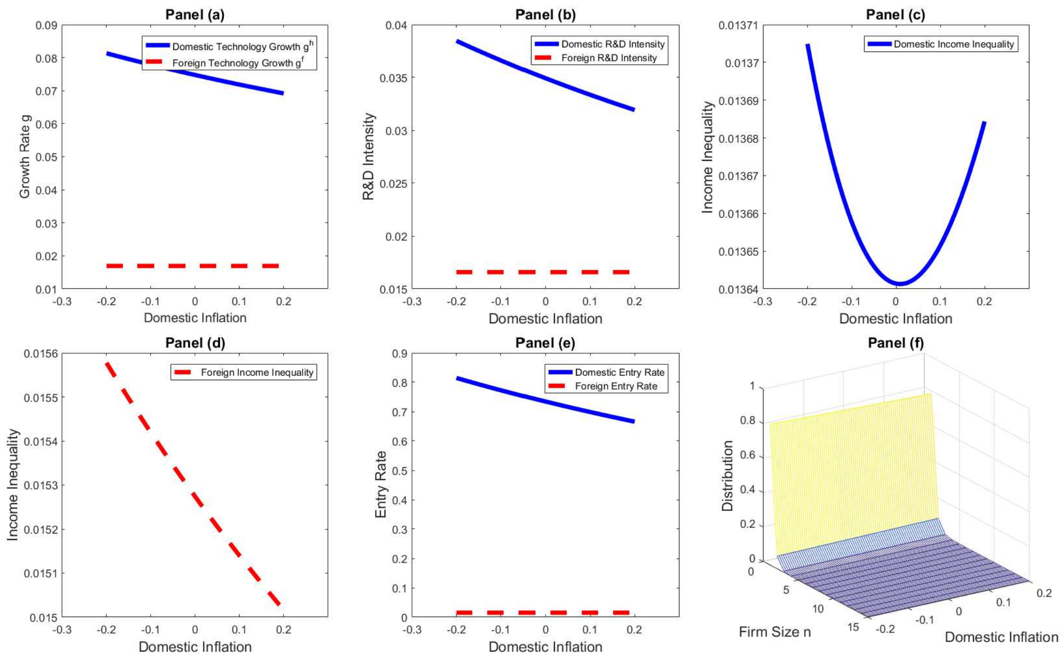

Figure 6: Effects of Domestic Inflation (U-shaped Calibration).

than a large open economy, as implied by Proposition 2. As shown in Figure 7 – Panel (c), the U-shaped relationship between inflation and income inequality disappears if domestic country becomes small. This model implication is also consistent with the empirical evidence to be presented in the next subsection.

In the presence of a U-shaped relationship, it is natural to ask what the inequality-minimizing inflation would be given any level of foreign inflation. We address this question and plot the best responses of domestic inflation in Figure 8, where foreign inflation is allowed to vary from -20% to 20% and parameter values come from the U-shaped calibration. Notice that the best responses of foreign inflation to domestic inflation are trivial, since the foreign country can always minimize its income inequality by setting its inflation at the lowest possible value when the domestic country has a higher technology growth rate. Figure 8 suggests that the central bank should gradually raise domestic inflation in response to increased foreign inflation if the objective of monetary policy is to minimize domestic income inequality.

In Figures 9 and 10, we report the corresponding economic growth rates and income inequality coefficients under the inequality-minimizing inflation, in comparison to three alternative scenarios where inflation rates are set constant at 2.5%, 5% and 10%, respectively.[19] It is observed that relatively high inflation (i.e. 10%) raises income inequality and simultaneously leads to the lowest economic growth rate, which seems to be the least favorable. When inflation is set constant at 2.5%, the resulting income inequality is higher than the minimized income inequality, but

[19]The horizontal axis is scaled by 100, and restricted between -6% and 6% of foreign inflation.

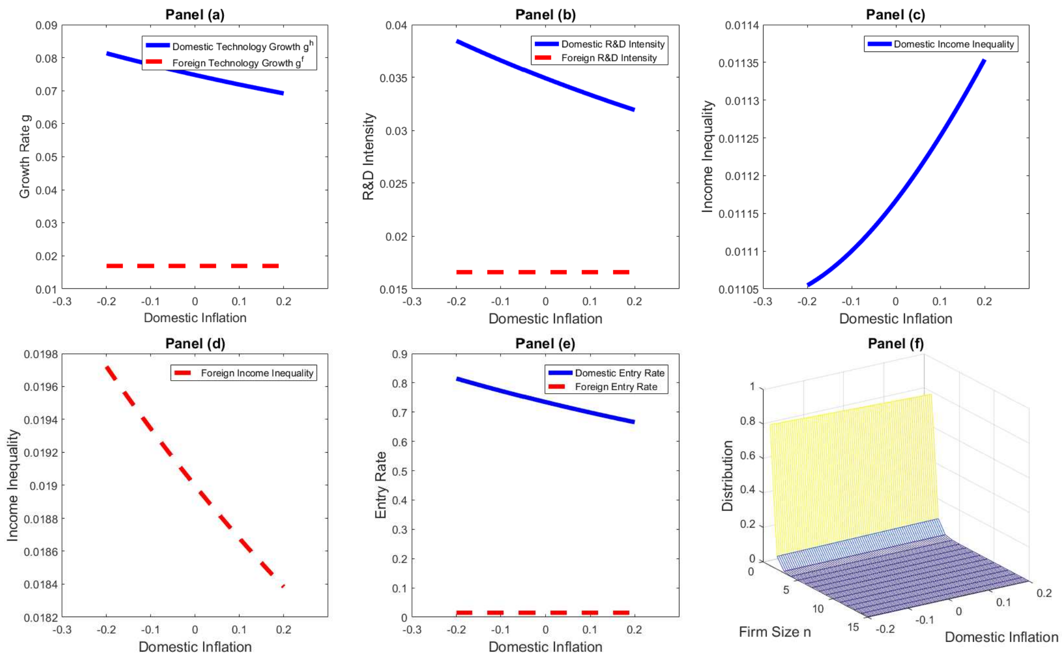

Figure 7: Effects of Domestic Inflation (U-shaped Calibration, $\alpha = 0.6$).

the difference is not substantial. This observation is partly attributed to the fact that inequality-minimizing inflation, given that foreign inflation varies between -6% and 6%, is around 1%, and within its close neighborhood, the effect of lower or higher domestic inflation on income inequality is not quantitatively sizable. As suggested in Figure 8, however, higher domestic inflation would induce a relatively large growth-retarding effect. Therefore, relatively low inflation seems more desirable if both economic growth and income inequality enter the central bank's objective function.

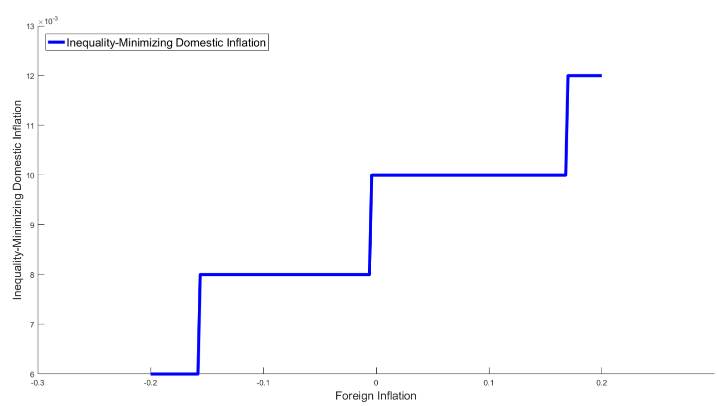

Figure 8: Inequality-Minimizing Level of Domestic Inflation in Response to Foreign Inflation

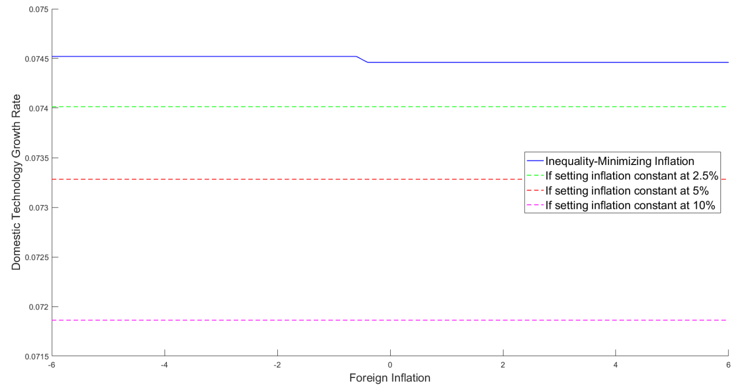

Figure 9: Inequality-Minimizing Level of Domestic Inflation: Economic Growth

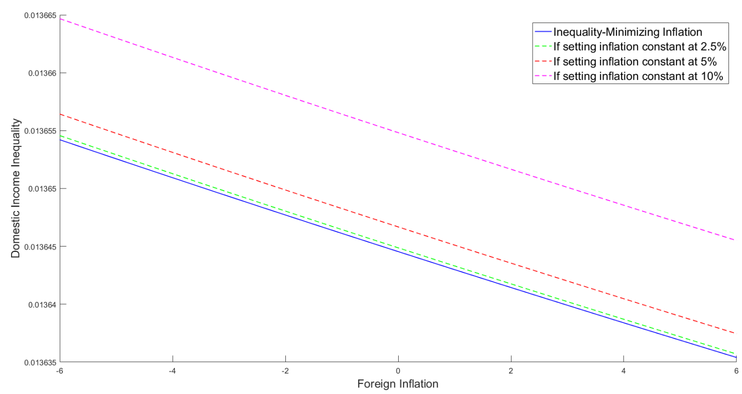

Figure 10: Inequality-Minimizing Level of Domestic Inflation: Income Inequality

5.4 Empirical evidence

Although some existing literature clearly documents a positive correlation between inflation and income inequality (see Romer and Romer (1998), and Albanesi (2007b)), the effect of inflation on income distribution remains largely ambiguous. In general, a positive inflation-inequality relationship implies that exploiting expansionary monetary policy to promote economic growth would unavoidably lead to income distribution that is even more unequal. However, Galli and van der Hoeven (2001) provide empirical evidence that the relationship between inflation and income inequality is U-shaped, which implies that higher inflation aiming to boost economic growth could possibly mitigate income inequality at the same time if the initial inflation is sufficiently moderate; and raising inflation enlarges the income gap between the rich and the poor once the initial inflation rate is greater than a certain threshold value. Exploiting data on the US and other 15 OECD countries, Galli and van der Hoeven (2001) find that the inequality-minimizing inflation rate is around 8%. In a sharp contrast to this result, based on a panel data set covering exclusively high income countries, Chu, Cozzi, Fan, Furukawa and Liao (2019b) find a hump-shaped relationship between inflation and income inequality, indicating the existence of an otherwise inequality-maximizing inflation rate that is estimated to be around 12%.

While not aiming to fully resolve the empirical discrepancy, the empirical practice of this study provides some novel evidence that the relationship between inflation and income inequality depends on the potential influence of a country to the world economy. In particular, it is found that the inflation-inequality relationship among high influence economies (HIEs) is U-shaped, whereas the relationship among low influence economies (LIEs) seems to be increasing.

To measure the global influence of an economy, this paper constructs a simple index, which takes the following steps. First, we compute the correlation between a country's GDP growth rate and the GDP growth rate in the US. Second, we calculate the ratio of a country's GDP to the US GDP. Third, we collect data on the Chinn-Ito index to measure a country's financial openness. Finally, the index is created by taking the product of the correlation coefficient, the GDP ratio and the degree of financial openness. Index values and ranking are reported in Table B.1.

Based on the index values, we categorize the investigated countries into two groups, namely HIEs and LIEs, and estimate the following static cross-country regression for each group independently:

$$INE_{i,j} = \theta_{1,j}\pi_{i,j} + \theta_{2,j}\pi_{i,j}^2 + H_{INE}X_{i,j} + \varepsilon_{i,j} \tag{44}$$

where INE represents income inequality, π denotes inflation; H_{INE} is the coefficient matrix on a vector of control variables, X, which incorporates unemployment rates and measures of economic freedom and degree of openness, and i and j are country and group indices, respectively. In (44), squared-inflation is included to examine the nonlinear effect of inflation on inequality, and the unemployment rate is exploited to gauge the domestic labor market conditions, which, in theory, could directly affect income distribution. In addition, similar to the estimation strategy in Albanesi (2007b), all variables in (44) are long-run averages of all available observations in a country (or region) over the entire sample period. We choose not to exploit the panel data approach, because we find that different specifications on country- and year-fixed effects yield apparently contradicting results; exploring the sources leading to the contradicting evidence would further digress away from the primary goal of this study.

Constrained by the availability and the completeness of observations on investigated variables, our empirical practice collects yearly data on 65 high income and upper middle income economies, ranging from 2000 to 2015.[20] In this paper, Gini coefficient published by the World Income Inequality Database (WIID May 2020) is adopted as the measure of income inequality. Economic freedom and financial openness are measured by the Fraser Index and the Chinn-Ito Index, respectively.[21] Data on GDP, inflation, unemployment rate, and trade openness are collected from the World Bank Open Data.

[20] It is worth noting that our data set contains a larger number of countries than most of the existing studies.
[21] Please see Aizenman *et al.* (2010) for the description on the Chinn-Ito Index

Notice that WIID reports Gini coefficient for around 110 high income and upper middle income economies. Unfortunately, some economies are eliminated from our data set precisely due to unavailability and/or incompleteness of data on investigated variables. Constructing the index that measures a country's global influence requires observations on GDP and Chinn-Ito index, which instantly reduces the number of countries in our data set to 96. Removal of countries with zero or only one complete observation over the studied window from 2000 to 2015 yields a data set consisting of 70 economies. A complete observation is defined as an observation containing no missing value on any of the five variables in the regression (namely Gini coefficient, inflation, unemployment rate, economic freedom and trade openness) of a given year. In fact, most of the missing values in a country happen to the Gini coefficient. We choose to eliminate countries with only one complete observation, since one observation in an arbitrary year seems unable to accurately capture the long-run relationship between inflation and income inequality. In addition, after further eliminating 5 countries (around 7% in our data set) with the highest long-run inflation rate (which exceeds 11% per annum), 65 economies are naturally left in the finalized data set. Figures 11 to 14 visualize the data.

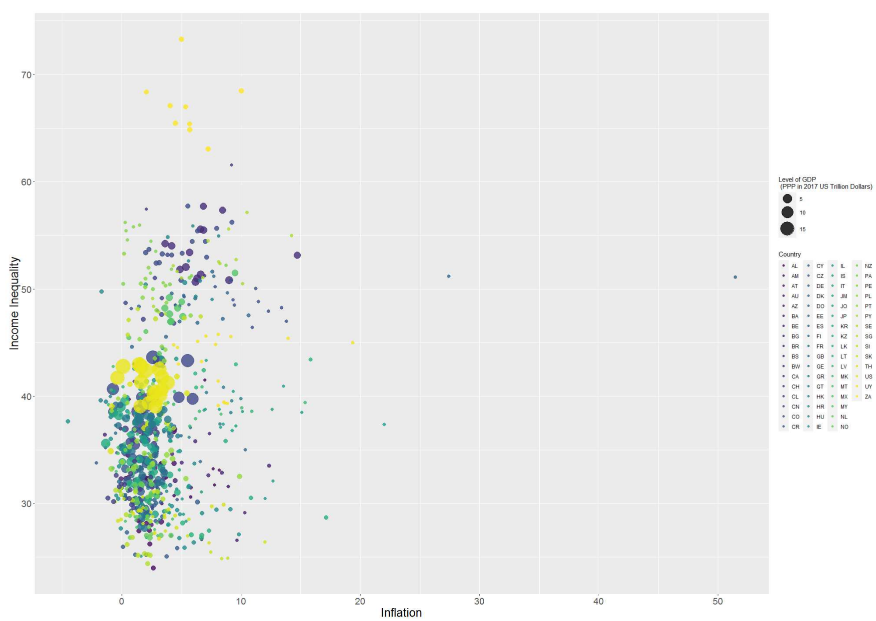

Figure 11: Scatter Plot of Observations for All Countries (Panel Data)

In the baseline regression, the group of HIEs incorporates the 16 economies ranked top in the list (from US to Australia) over the 2000-2015 window. Consequently, the rest of the economies on the ranking list fall into the LIEs category. Tables 2 and 3 report the coefficient estimates for HIEs and LIEs, respectively. As shown under Columns (1) and (3) in Table 2, when inflation and squared-inflation are both present, our cross-country regression yields an estimate of coefficient on inflation that is negative and statistically significant at 10% level, and an estimate of coeffi-

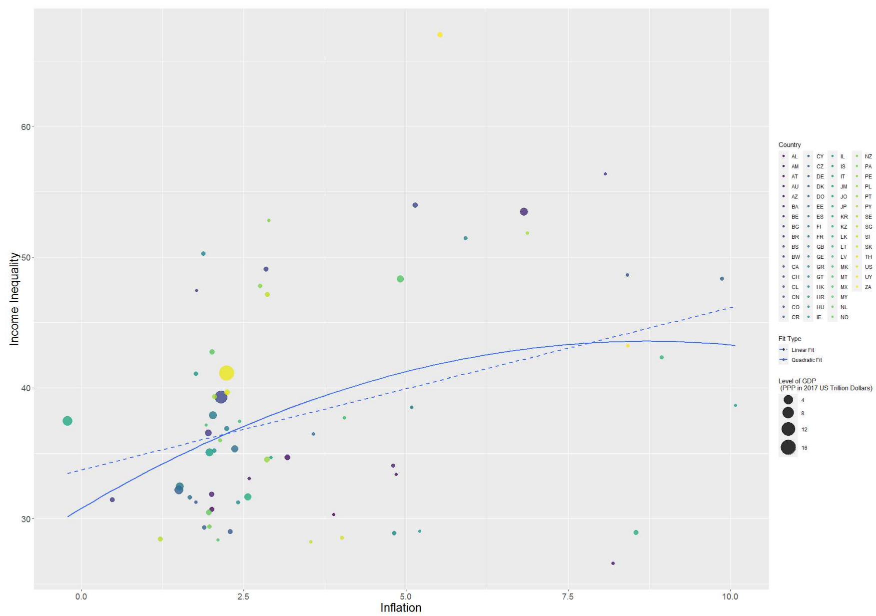

Figure 12: Scatter Plot of Observations for All Countries (Cross-sectional Data)

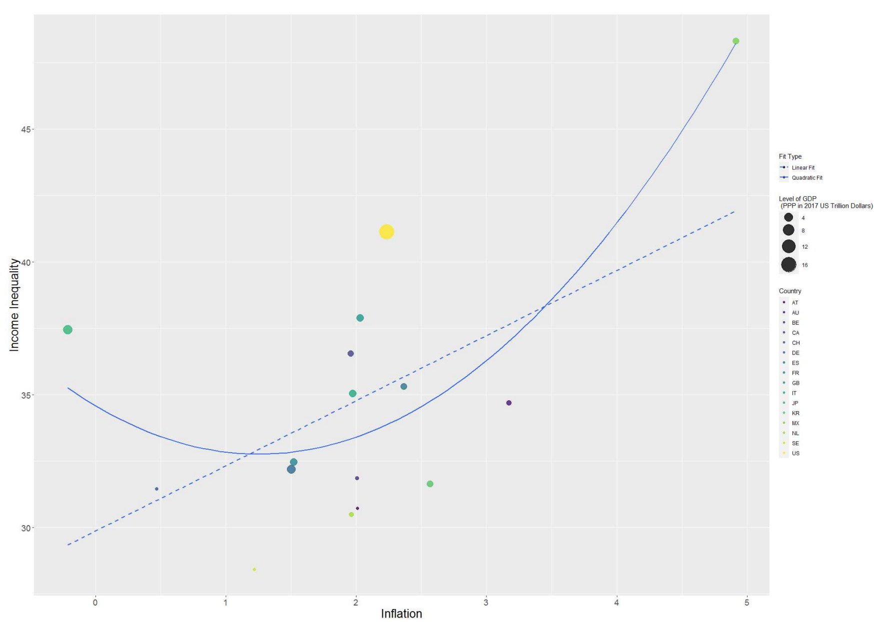

Figure 13: Inflation and Income Inequality in HIEs

cient on squared-inflation that is strongly positive at 1% level, despite exclusion of the control variables. Combined with the evidence that estimation excluding squared-inflation leads to a positive but insignificant estimate of coefficient on inflation, it implies that omitting squared-inflation seems unable to adequately capture the empirical relationship between inflation and income inequality among HIEs, which is likely to be U-shaped. According to our baseline esti-

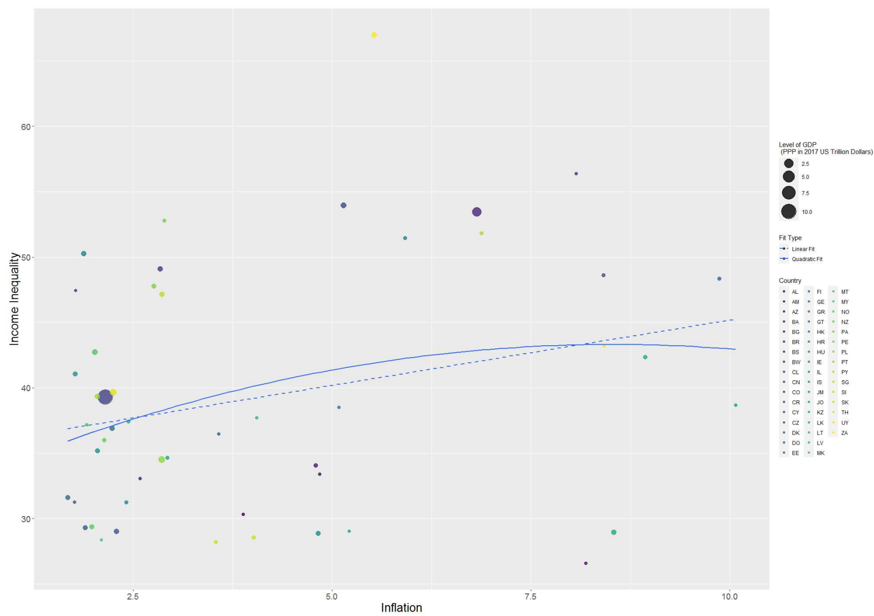

Figure 14: Inflation and Income Inequality in LIEs

mation, the inequality-minimizing inflation rate is around 1.14%.

In an alternative practice, we further narrow down the list of HIEs to 12 countries by removing the 4 bottom countries (namely Sweden, Switzerland, Austria and Australia) ranked in the HIEs list from the baseline analysis. As shown under Columns (4) to (6) in Table 2, the empirical evidence for HIEs under the alternative specification remains consistent with that of the baseline estimation, and the U-shaped inflation-inequality relationship is observed to be even stronger. Even though the magnitude of estimated coefficients on inflation measures are slightly higher, the model-implied inequality-minimizing inflation rate is still around 1%. Concerning that our index-based measurement of global influence may not adequately capture a country's potential impact on the world economy,[22] as a robustness check, we define HIEs as the 7 largest economies in our full sample. Columns (7) – (9) suggest that the U-shaped relationship between inflation and income inequality among HIEs is robust to the GDP-based measurement of global influence. However, it is worth noting that statistical inference under the robustness check is subject to caveat, due to small sample size and low degree of freedom.

For LIEs, as shown in Table 3, it is found that incorporating squared-inflation into regression is likely to incorrectly capture the inflation-inequality relationship. Across all model specifications, none of the estimation yields statistically significant estimate of coefficient on squared-inflation. In particular, under the index-based measurement of global influence, coefficient estimate of inflation becomes insignificant once squared-inflation is incorporated. When only linear

[22]For example, due to low correlation with the US GDP growth rate and lacking financial openness, China, the second largest economy in the world, is not categorized as an HIE using the index-based measurement.

effect of inflation on income inequality is permitted, all model specifications imply a positive inflation-inequality relationship, which is in line with Albanesi (2007b). According to our estimation results, a one-percent increase in inflation raises Gini coefficient by around 1.04 to 1.27 among LIEs.

Table 2: Effect of Inflation on Income Inequality – High Influence Economies.

	Index-Based						Robustness: GDP-Based		
	Baseline			Alternative					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
π	-2.8960*	2.0094	-2.7506*	-3.2829**	2.7717**	-3.0746*	-11.0249***	2.3117***	-2.6986***
	(1.5734)	(1.1601)	(1.3210)	(1.1545)	(1.1046)	(1.4502)	(0.6506)	(0.1839)	(0.0220)
π^2	1.1547***		1.2070***	1.1695***		1.4529***	6.0819***		2.3145***
	(0.2645)		(0.2535)	(0.2101)		(0.3589)	(0.3588)		(0.0103)
Unemployment		-0.3072	0.1834		-0.3383	0.1661		-1.0430**	-0.7509***
		(0.2566)	(1.758)		(-0.2626)	(-0.2345)		(0.2389)	(0.0011)
Openness		-0.0797***	-0.0509*		-0.0890**	-0.0446		-0.1198**	-0.0692***
		(0.0254)	(0.0240)		(0.0283)	(0.0237)		(0.0123)	(0.0004)
Economic Freedom		-1.2108	2.5106		0.2058	6.2738**		0.4998	0.4924***
		(3.0278)	(2.6339)		(2.0887)	(2.0853)		(0.2857)	(0.0040)
Specification				Remove AU, AT, SE and CH from Baseline			7 Largest Economies US, CN, JP, DE, FR, GB, and IT		
Observations	16	16	16	12	12	12	7	7	7
p-value	0.0031	0.0197	0.0043	0.0099	0.0258	0.0013	0.0026	0.0238	0.0012

Notes: $***p \leq 0.01$, $**p \leq 0.05$, $*p \leq 0.1$. Robust standard errors are reported in parentheses. Constant terms are omitted.

6 Conclusion

In this study, we build an open-economy microfounded model of firm-level innovation and quality-ladder growth. Incumbents and entrants engage in different types of R&D activities for innovation to expand their production capacity by increasing the number of product lines. In addition, this model takes into consideration heterogeneous asset holdings of households and CIA constraints on R&D investment; the former is the source of income inequality whereas the latter introduces monetary policy. The model enables us to explore the cross-country effects of inflation on innovation, economic growth, and income inequality.

We find that higher domestic inflation decreases domestic aggregate technology through a lower entry rate of new firms and does not have an impact on foreign aggregate technology. Given that economic growth in a country is driven by the growth rates of domestic and foreign technology, domestic economic growth is decreasing in both domestic inflation and foreign in-

Table 3: Effect of Inflation on Income Inequality – Low Influence Economies.

	Index-Based						Robustness: GDP-Based		
	Baseline			Alternative					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
π	2.6765*	1.0399**	2.5958	3.2878	1.1515**	3.1182	3.8524*	1.2732**	3.7790*
	(2.9476)	(0.5101)	(2.8661)	(2.3481)	(0.4943)	(2.2917)	(2.2293)	(0.5223)	(2.2538)
π^2	-0.1569		-1.1449	-0.2042		-0.1864	-0.2477		-0.2366
	(0.2597)		(0.2559)	(0.2112)		(0.2084)	(0.2017)		(0.2026)
Unemployment		0.0874	0.0701		0.1231	0.0934		0.1247	0.0977
		(0.2649)	(0.2550)		(0.2566)	(0.2470)		(0.2494)	(0.2378)
Openness		-0.0047	-0.0043		0.0028	0.0021		0.0021	0.0014
		(0.0252)	(0.0253)		(0.0237)	(0.0237)		(0.0231)	(0.0229)
Economic Freedom		0.8389	0.8538		-0.0297	0.1546		-0.0140	0.3954
		(2.6282)	(2.6459)		(2.3491)	(2.3644)		(2.5894)	(2.6107)
Specification				Add AU, AT, SE and CH to Baseline			Consistent with GDP-based HIEs		
Observations	49	49	49	53	53	53	58	58	58
p-value	0.0031	0.0197	0.0043	0.0099	0.0258	0.0013	0.0026	0.0238	0.0012

Notes: $***p \leq 0.01$, $**\,p \leq 0.05$, $*p \leq 0.1$. Robust standard errors are reported in parentheses. Constant terms are omitted.

flation. Moreover, domestic inflation affects domestic income inequality through the channels of the real interest rate and the asset value relative to wage. We show that the interplay of these two channels causes ambiguity on the relationship between domestic inflation and domestic income inequality, which depends on the growth rate of foreign technology. Specifically, higher domestic inflation yields a U-shaped (positive) effect on domestic income inequality if the growth rate of foreign technology is sufficiently low (high). By the features of small open economies, a large-sized (small-sized) country normally exhibits a low (high) growth rate of foreign technology. Therefore, the above result implies that the implication of domestic inflation on domestic income inequality also would be contingent on the size of the country. Nevertheless, higher foreign inflation leads to a negative effect on domestic income inequality by only operating through the interest-rate channel.

We estimate the parameters of the model by using data in the US and Eurozone countries and numerically evaluate the cross-country effects of inflation on entry of new entrants, firm size distribution, economic growth, and income inequality. The result is in line with the implications predicted by our model across various sets of parametrization. In particular, the benchmark parametrization shows that domestic inflation is negatively correlated with domestic economic growth and positively correlated with domestic income inequality, indicating that the target of "high growth and low inequality" could be potentially attained by implementing appropriate monetary policy. Furthermore, we use cross-country data to perform an empirical analysis, which shows evidence that the correlation between domestic inflation and domestic income inequality is U-shaped (positive) if the country size is large (small).

As for future research in this literature, one direction is to reexamine the cross-country effects of inflation on income inequality by introducing more heterogeneity on firms' type, such as external innovation versus internal innovation as in Akcigit and Kerr (2018), and high-type firms versus low-type firms in terms of their innovative capacity as in Acemoglu, Akcigit, Alp, Bloom and Kerr (2018). Another direction is to pursue the model implications for other policy regimes. It may be fruitful extensions to consider the implementation of patent policy and fiscal policy, given that the dimensions by which these policy instruments affect resource allocation can be different. Therefore, the effects of these two policy regimes on income inequality may not be identical to those of monetary policy.[23] The third direction is to have more empirical evidence on the determinants of the CIA constraints, which potentially differ in magnitude across different types of innovation, as theoretically analyzed by Huang, Yang and Zheng (2019) and Zheng, Huang and Yang (2019). We leaving these interesting extensions for future research.

[23]Nevertheless, when fiscal policy, such as research subsidies to incumbents and entrants, are present in the current model with non-distortionary taxes, increasing research subsidies and decreasing inflation would generate the same effects on the economy (e.g., economic growth and income inequality) by reallocating labor from R&D to production. In other words, research subsidies that are financed by distortionary taxes could create different impacts on the economy, as compare to the current analysis.

Appendix A Proofs of propositions

A.1 Proof of Lemma 2

According to Lemma 2, $\{a_t^h, b_t^h, c_t^h, w_t^h, \tau_t^h\}$ all grow at the same steady-state rate of g along the BGP. Thus, d_t^h also grows at the rate of g. Using (36), we have

$$\frac{c_t^h - w_t^h - \tau_t^h}{d_t^h} = r - \frac{\dot{d}_t^h}{d_t^h} = \rho > 0. \tag{A.1}$$

Therefore, the coefficient on $\theta_{d,t}^h(s)$ in (38) is always positive. It then implies that for any given i^h and i^f, $\dot{\theta}_{dt}^h(s) = 0$ for all $t > 0$ is the only solution of (38) to achieve stability. Moreover, imposing $\dot{\theta}_{dt}^h(s) = 0$ on (38) yields the steady-state value of $\theta_{c,t}^h(s)$ given by

$$\theta_{c,0}^h(s) = 1 - \frac{\rho[1 - \theta_{d,0}^h(s)]}{c_t^h / d_t^h}. \tag{A.2}$$

A.2 Proof of Proposition 2

Differentiating (43) with respect to i^f yields

$$\frac{\partial (rd^h / w_t^h)}{\partial i^f} = \left[\phi^h(1 + \xi^h i^h) + \frac{\xi^h \lambda^h (1 + \phi^h \rho)}{1 + \lambda^h + \xi^h i^h} - \xi^h \rho\right] \frac{\partial g}{\partial i^f} < 0, \tag{A.3}$$

so the effect of i^f on domestic income inequality is monotonically decreasing.

Additionally, using (31) and (32) to rewrite (43) as

$$\frac{rd_t^h}{w_t^h} = \left[\Phi + \ln(1 + \lambda^h) \frac{\lambda^h (1 - \alpha)(1 + \phi^h \rho)}{\phi^h (1 + \lambda^h + \xi^h i^h)}\right] \times \left[\phi^h(1 + \xi^h i^h) + \frac{\xi^h \lambda^h (1 + \phi^h \rho)}{1 + \lambda^h + \xi^h i^h} - \xi^h \rho\right], \tag{A.4}$$

where

$$\Phi = \rho + \alpha g^f + (1 - \alpha) \ln(1 + \lambda^h) \left[(1 - \gamma^h) \left(\frac{\gamma^h \phi^h}{\varphi^h}\right)^{\frac{\gamma^h}{1 - \gamma^h}} - \rho\right] > 0$$

is independent of i^h. Differentiating (A.4) with respect to i^h yields

$$
\begin{aligned}
&\frac{\partial(rd_t^h/w_t^h)}{\partial i^h} \gtrless 0 \\
\Leftrightarrow & -\frac{\lambda^h\xi^h(1-\alpha)(1+\phi^h\rho)\ln(1+\lambda^h)}{\phi^h(1+\lambda^h+\xi^h i^h)^2}\left[\phi^h(1+\xi^h i^h)+\frac{\xi^h\lambda^h(1+\phi^h\rho)}{1+\lambda^h+\xi^h i^h}-\xi^h\rho\right] \\
& + \left[\Phi+\ln(1+\lambda^h)\frac{\lambda^h(1-\alpha)(1+\phi^h\rho)}{\phi^h(1+\lambda^h+\xi^h i^h)}\right]\times\left[\phi^h\xi^h-\frac{\xi^h\lambda^h(1+\phi^h\rho)\xi^h}{(1+\lambda^h+\xi^h i^h)^2}\right]\gtrless 0 \\
\Leftrightarrow & -\frac{\ln(1+\lambda^h)[\lambda^h(1-\alpha)(1+\phi^h\rho)]\xi^h(1+\xi^h i^h)}{(1+\lambda^h+\xi^h i^h)^2}-\frac{\ln(1+\lambda^h)\left[\lambda^h(1-\alpha)(1+\phi^h\rho)\right](\xi^h)^2\lambda^h(1+\phi^h\rho)}{\phi^h(1+\lambda^h+\xi^h i^h)^2} \\
& + \frac{\ln(1+\lambda^h)[\lambda^h(1-\alpha)(1+\phi^h\rho)](\xi^h)^2\rho}{(1+\lambda^h+\xi^h i^h)^2}+\Phi\left[\phi^h\xi^h-\frac{\xi^h\lambda^h(1+\phi^h\rho)\xi^h}{(1+\lambda^h+\xi^h i^h)^2}\right] \\
& + \frac{\ln(1+\lambda^h)[\lambda^h(1-\alpha)(1+\phi^h\rho)\xi^h]}{1+\lambda^h+\xi^h i^h}-\frac{\ln(1+\lambda^h)[\lambda^h(1-\alpha)(1+\phi^h\rho)]\xi^h\lambda^h(1+\phi^h\rho)\xi^h}{\phi^h(1+\lambda^h+\xi^h i^h)^3}\gtrless 0 \\
\Leftrightarrow & -\frac{\ln(1+\lambda^h)[\lambda^h(1-\alpha)(1+\phi^h\rho)]\xi^h}{(1+\lambda^h+\xi^h i^h)^2}\left[(1+\xi^h i^h)-\xi^h\rho-(1+\lambda^h+\xi^h i^h)\right]+\Phi\left[\phi^h\xi^h-\frac{\xi^h\lambda^h(1+\phi^h\rho)\xi^h}{(1+\lambda^h+\xi^h i^h)^2}\right] \\
& -\frac{2\ln(1+\lambda^h)[\lambda^h(1-\alpha)(1+\phi^h\rho)](\xi^h)^2\lambda^h(1+\phi^h\rho)}{\phi^h(1+\lambda^h+\xi^h i^h)^3}\gtrless 0 \\
\Leftrightarrow & \underbrace{\frac{\ln(1+\lambda^h)[\lambda^h(1-\alpha)(1+\phi^h\rho)]\xi^h}{\phi^h(1+\lambda^h+\xi^h i^h)^3}}_{\Gamma_1}\underbrace{\left[\phi^h(\lambda^h+\xi^h\rho)(1+\lambda^h+\xi^h i^h)-2\xi^h\lambda^h(1+\phi^h\rho)\right]}_{\Gamma_2} \\
& + \Phi\xi^h\underbrace{\left[\phi^h-\frac{\lambda^h(1+\phi^h\rho)\xi^h}{(1+\lambda^h+\xi^h i^h)^2}\right]}_{\Gamma_3}\gtrless 0.
\end{aligned}
\tag{A.5}
$$

Given Γ_1 is positive for all i^h, the sign of $\partial(rd_t^h/w_t^h)/(\partial i^h)$ depends on the signs of Γ_2 and Γ_3. It is straightforward to see that both Γ_2 and Γ_3 are increasing in i^h, and they are positive if the following conditions are satisfied:

$$
1+\lambda^h+\xi^h i^h \geq \frac{2\xi^h\lambda^h(1+\phi^h\rho)}{\phi^h(\lambda^h+\xi^h\rho)}, \quad \text{and} \quad 1+\lambda^h+\xi^h i^h \geq \sqrt{\frac{\lambda^h\xi^h(1+\phi^h\rho)}{\phi^h}}. \tag{A.6}
$$

Recall that there exists an upper bound $\hat{i}^h$ that ensures a nonnegative entry rate in country h such that

$$
\begin{aligned}
x_e^h \geq 0 &\Leftrightarrow \frac{\lambda^h(1/\varphi^h+\rho)}{1+\lambda^h+\xi^h i^h}-\gamma^h\left(\frac{\gamma^h\phi^h}{\varphi^h}\right)^{\frac{\gamma^h}{1-\gamma^h}}-\rho \geq 0 \\
&\Leftrightarrow 1+\lambda^h+\xi^h\hat{i}^h \leq \frac{\lambda^h(1/\varphi^h+\rho)}{\gamma^h\left(\frac{\gamma^h\phi^h}{\varphi^h}\right)^{\frac{\gamma^h}{1-\gamma^h}}+\rho}.
\end{aligned}
\tag{A.7}
$$

Suppose that

$$\frac{\lambda^h(1/\varphi^h+\rho)}{\gamma^h\left(\frac{\gamma^h\phi^h}{\varphi^h}\right)^{\frac{\gamma^h}{1-\gamma^h}}+\rho} \geq \max\left\{\frac{2\xi^h\lambda^h(1+\phi^h\rho)}{\phi^h(\lambda^h+\xi^h\rho)}, \sqrt{\frac{\lambda^h\xi^h(1+\phi^h\rho)}{\phi^h}}\right\}, \tag{A.8}$$

which can be supported under a sufficiently small γ^h. In this case, there must exist a value $\bar{i}^h < \hat{i}^h$ ensuring that both Γ_2 and Γ_3 are positive. It then follows that $[\partial(rd_t^h/w_t^h)/(\partial i^h)]_{i^h=\bar{i}^h} > 0$ is also positive.

Next, we examine the value of $\partial(rd_t^h/w_t^h)/\partial i^h$ at $i^h = 0$. We find that for a sufficiently small discount rate ρ, $\Gamma_2|_{i^h=0} < 0$ and $\Gamma_3|_{i^h=0} > 0$ hold such that

$$\begin{aligned}\Gamma_2|_{i^h=0} < 0 \Leftrightarrow & \phi^h(\lambda^h+\xi^h\rho)(1+\lambda^h) - 2\xi^h\lambda^h(1+\phi^h\rho) < 0 \\ \Leftrightarrow & \rho < \frac{\lambda^h[2\xi^h - \phi^h(1+\lambda^h)]}{\xi^h\phi^h(1-\lambda^h)},\end{aligned} \tag{A.9}$$

for a general value of $\lambda^h < 1$,[24] and

$$\begin{aligned}\Gamma_3|_{i^h=0} > 0 \Leftrightarrow & \phi^h(1+\lambda^h)^2 > \lambda^h\xi^h(1+\phi^h\rho) \\ \Leftrightarrow & \rho < \frac{\phi^h(1+\lambda^h)^2 - \lambda^h\xi^h}{\lambda^h\xi^h\phi^h}.\end{aligned} \tag{A.10}$$

Conditions in (A.9) and (A.10) can be further summarized as[25]

$$\rho < \min\left\{\frac{\lambda^h[2\xi^h - \phi^h(1+\lambda^h)]}{\xi^h\phi^h(1-\lambda^h)}, \frac{\phi^h(1+\lambda^h)^2 - \lambda^h\xi^h}{\lambda^h\xi^h\phi^h}\right\}. \tag{A.11}$$

Given (A.11), we find that for a sufficiently large value of the foreign technology growth rate g^f (i.e., a sufficiently large Φ), $\partial(rd_t^h/w_t^h)/\partial i^h$ at $i^h = 0$ can be positive. As i^h rises, the absolute value of $\Gamma_1\Gamma_2$ becomes smaller, whereas $\Phi\xi^h\Gamma_3$ becomes larger and dominates the product of $\Gamma_1\Gamma_2$. This result implies that $\partial(rd_t^h/w_t^h)/\partial i^h$ and country h's income inequality is a monotonically increasing function of i^h. In contrast, for a sufficiently small value of the foreign technology growth rate g^f (i.e., a sufficiently small Φ), we obtain $[\partial(rd_t^h/w_t^h)/\partial i^h]|_{i^h=0} < 0$. Therefore, $\partial(rd_t^h/w_t^h)/\partial i^h$ and country h's income inequality first decreases in i^h and eventually increases in i^h.

Appendix B Data description

[24] The literature generally documents that the quality step size of innovation lies in the range of $[1.05, 1.2]$. In our model, it means that $1+\lambda^h \in [1.05, 1.2]$ or equivalently $\lambda^h \in [0.05, 0.2] < 1$.

[25] Parameters are required to ensure a positive ρ.

B.1 Data construction

Yearly data on the investigated variables for all available high income and upper middle income economies is described as follows:

(1) GDP PPP: GDP (Level) Purchasing Power Parity (constant 2017 International dollar), downloaded from the World Bank Database; Series "NY.GDP.PCAP.PP.KD".

(2) Import Share in GDP: Import values as a percentage of GDP, downloaded from the World Bank Database; Series "NE.IMP.GNFS.ZS".

(3) Export Share in GDP: Export values as a percentage of GDP, downloaded from the World Bank Database; Series "NE.EXP.GNFS.ZS".

(4) Inflation: Annual percentage change in Consumer Prices, downloaded from the World Bank Database; Series "FP.CPI.TOTL.ZG".

(5) Unemployment: ILO estimate of the unemployment rate, downloaded from the World Bank Database; Series "SL.EMP.TOTL.SP.ZS".

(6) Financial Openness: Chinn-Ito Index, published by Aizenman, Chinn and Ito in the Trilemma Indexes (https://urldefense.proofpoint.com/v2/url?u=http-3A__web.pdx.edu_&d=DwIGAg&c=KXX
8MbOxd1NuZkcSBymGmgo&r=6gyBWAoC_Www1SIRMhFksM6SkdeTWmTaCTAiDzs8NSo&m=o8NCmRQFb

(7) Gini Coefficient: Downloaded from the World Income Inequality Database (WIID May 2020).

Given the above series, the growth rate of GDP is computed as the annual percentage change in GDP per capita, and the degree of economic freedom is defined as the sum of import and export shares in GDP. For the conventional measure of income inequality, WIID occasionally reports multiple observations on Gini coefficient for a particular country within a year, which are either collected from different sources or computed according to different criteria. Whenever it happens, our strategy of constructing the Gini coefficient series is to take the average of all available observations for country i in year t.

Table B.1: Ranking based on Index Value – High Income and Upper Middle Income Economies

Rank	Country	Corr with U.S. GDP Growth Rate	GDP relative to U.S.	Financial Openness	Index
–	United States	1.0000	1.0000	–	–
1	Japan	0.8731	0.2907	1.0000	0.2538
2	Germany	0.6242	0.2315	1.0000	0.1445
3	United Kingdom	0.8849	0.1590	1.0000	0.1407
4	France	0.8019	0.1643	1.0000	0.1318
5	Italy	0.7221	0.1542	1.0000	0.1113
6	Mexico	0.8367	0.1215	0.6683	0.0679
7	Canada	0.7462	0.0882	1.0000	0.0658
8	Spain	0.6263	0.1008	1.0000	0.0632
9	Netherlands	0.6155	0.0512	1.0000	0.0315
10	Korea, Rep.	0.5414	0.0938	0.5292	0.0269
11	Belgium	0.8225	0.0306	0.9775	0.0246
12	Sweden	0.8310	0.0265	1.0000	0.0220
13	Switzerland	0.6649	0.0293	1.0000	0.0195
14	Austria	0.7147	0.0258	1.0000	0.0184
15	Australia	0.3726	0.0571	0.7372	0.0157
16	Hong Kong SAR, China	0.7834	0.0200	1.0000	0.0157
17	Denmark	0.9069	0.0172	1.0000	0.0156
18	Norway	0.8120	0.0175	1.0000	0.0142
19	Czech Republic	0.7282	0.0199	0.9448	0.0137
20	Singapore	0.6230	0.0210	1.0000	0.0131
21	Brazil	0.2013	0.1593	0.4069	0.0131
22	Chile	0.7242	0.0198	0.7977	0.0115
23	Finland	0.7475	0.0145	1.0000	0.0108
24	Hungary	0.7694	0.0148	0.9260	0.0105
25	Portugal	0.5224	0.0198	1.0000	0.0104
26	Malaysia	0.8226	0.0325	0.3713	0.0099
27	Thailand	0.6076	0.0535	0.2908	0.0095
28	Ireland	0.5807	0.0146	1.0000	0.0085
29	Greece	0.3633	0.0218	0.9528	0.0076
30	Israel	0.4865	0.0150	0.9362	0.0068
31	China	0.0665	0.6024	0.1650	0.0066
32	New Zealand	0.6858	0.0095	1.0000	0.0065
33	Poland	0.2607	0.0503	0.4284	0.0056
34	Colombia	0.4343	0.0305	0.3713	0.0049
35	South Africa	0.6583	0.0361	0.1650	0.0039

Table B.1 (Continued): Ranking based on Index Value – High Income and Upper Middle Income Economies

Rank	Country	Corr with U.S. GDP Growth Rate	GDP relative to U.S.	Financial Openness	Index
36	Bulgaria	0.5471	0.0071	0.7094	0.0028
37	Guatemala	0.4697	0.0060	0.9823	0.0028
38	Lithuania	0.6942	0.0044	0.8911	0.0028
39	Croatia	0.6281	0.0061	0.6466	0.0025
40	Peru	0.1535	0.0157	1.0000	0.0024
41	Slovak Republic	0.5217	0.0076	0.5639	0.0022
42	Latvia	0.7351	0.0027	0.9887	0.0020
43	Slovenia	0.6198	0.0039	0.7935	0.0019
44	Estonia	0.8483	0.0021	1.0000	0.0018
45	Dominican Republic	0.3911	0.0067	0.6459	0.0017
46	Costa Rica	0.5125	0.0041	0.7877	0.0016
47	Kazakhstan	0.4611	0.0181	0.1650	0.0014
48	Sri Lanka	0.3280	0.0102	0.3950	0.0013
49	Armenia	0.6441	0.0015	1.0000	0.0010
50	Jamaica	0.6518	0.0016	0.8686	0.0009
51	Georgia	0.5434	0.0020	0.7347	0.0008
52	Bosnia and Herzegovina	0.5461	0.0023	0.6470	0.0008
53	Panama	0.1732	0.0043	1.0000	0.0007
54	Botswana	0.4031	0.0016	0.9269	0.0006
55	Cyprus	0.3758	0.0017	0.7117	0.0005
56	Azerbaijan	0.1574	0.0057	0.3267	0.0003
57	Malta	0.5017	0.0008	0.7380	0.0003
58	North Macedonia	0.4373	0.0015	0.4127	0.0003
59	Iceland	0.6418	0.0009	0.4324	0.0002
60	Paraguay	0.0775	0.0036	0.6358	0.0002
61	Albania	0.0450	0.0017	0.3536	0.0000
62	Bahamas	0.6698	0.0008	0.0000	0.0000
63	Jordan	-0.0031	0.0042	0.9962	0.0000
64	Uruguay	-0.0661	0.0032	1.0000	-0.0002

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