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Optimal Monetary Policy in a Two Country Model with Firm-Level Heterogeneity*

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Abstract

This paper studies non-cooperative monetary policy in a two country general equilibrium model where international economic integration is endogenised through firm-level heterogeneity and monopolistic competition. Economic integration between countries is a source of policy competition, generating higher long-run inflation, and increased gains from monetary cooperation.

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1. Introduction

The study of monetary policy interaction in open economies is typically undertaken within environments in which international economic integration is given - either goods are all traded or some goods are nontradable by assumption. In this paper, a simple two country general equilibrium model with firm-level heterogeneity is developed to study the joint determination of long-run inflation and international economic integration. There are two main findings. Monetary policy is more aggressive when economic integration is endogenous resulting in higher long-run inflation. The long-run welfare costs of inflation are magnified and this generates increased gains from monetary cooperation.

I consider a world economy in which each country is specialized in producing one good and each firm within a country produces one differentiated variety and competes in a monopolistically competitive market. Firms differ in their productivity but incur a common fixed cost of exporting so that only an endogenous subset of firms export.[1] Firms also fund working capital - which is complementary to labor - by borrowing from financial intermediaries.[2] When deciding on monetary policy in this environment, each government must consider how inflation affects the allocation of resources across firms within countries and the extent of economic integration between countries.

Without international trade (and with trade, but when countries cooperate over mone-

[1] These assumptions are made in the spirit of Melitz (2003). His theoretical analysis is motivated by empirical evidence that exporting firms are larger and more productive than non-exporters and that firms self-select into international trade. See Bernard and Jensen (1999), and more recently, Bernard *et al.* (2007).

[2] Working capital plays an important role over the business cycle. See Christiano et al. (2005) and Jermann and Quadrini (2011) and also the models of Fuerst (1992), Schlagenhauf and Wrase (1995), and Christiano *et al.* (1997).

tary arrangements) each government attempts to stimulate economic activity and raise output by lowering the interest rate. The Friedman rule is optimal. With trade in varieties - but when resource allocation and international economic integration are given - there is potential for policy competition between countries because each government can inflate, reduce own output, and influence the terms of trade. The extent to which governments inflate depends on the monopoly distortion in supply. With a relatively high distortion, the welfare gains from influencing the terms of trade are outweighed by the inefficiencies associated with higher long-run inflation, and the Friedman rule remains optimal.

When economic integration is endogenous there is an additional incentive to inflate. Inflating makes it more expensive for an individual firm to export their variety and raises the level of productivity required for a firm to generate positive export profits. In this case, when a country inflates, a smaller subset of firms choose to export, resources are re-allocated to these more productive firms, and average productivity rises across the export sector. In addition to reducing own output, optimal non-cooperative monetary policy dictates that each country reduce the proportion of firms that enter the export market.

The channel that generates inflation in my model has important implications for the welfare gains from monetary cooperation. First, the welfare gain from cooperation is greater because policy competition is more aggressive. Second, for a given level of inflation, the welfare gain is greater the more firms export. The reason is the following: the greater the proportion of firms that export, the more scope the policy maker has to inflate. Because inflating reduces the number of imported products available to the consumer, the negative welfare impact of inflation is magnified. Endogenising international economic integration and resource allocation across firms therefore generates higher inflation and increases the long-run welfare losses associated with non-cooperative policy.

This paper is related to two different strands of research in international macroeconomics. One strand seeks to understand the reasons for systematic inflation when countries interact. For example, Cooley and Quadrini (2003) argue that policy competition between countries leads to inflation with large welfare losses.[3] Arseneau (2007) shows that sufficiently large monopoly distortions can generate policies that coincide with the cooperative outcome. In this context, firm-level heterogeneity has important implications. It overturns the dampening effect of domestic monopoly distortions and generates a novel link between productivity and long-run inflation. A second strand of related research demonstrates how firm-level heterogeneity can have important macroeconomic implications because it generates endogenous tradability - for example, see Ghironi and Melitz (2005), Bergin and Glick (2007, 2009), Naknoi (2008), and Devereux and Hnatkovska (2011). However, this research does not consider how heterogeneity might alter policy decisions, which is the focus of this paper.

The remainder of the paper is organized as follows. Section 2 develops a two-country monetary model with firm-level heterogeneity. In sections 3 and 4 the model solution is presented and optimal non-cooperative policy and the welfare loss from non-cooperation are defined. The results are presented in section 5 and section 6 concludes.

2. The World Economy

[3] The natural alternative - summarized in Corsetti *et al.* (2011) - focuses on short-run stabilization policies and argues that the benefits of monetary cooperation are small (also see Pappa and Liu (2008) for an analysis of optimal stabilization policy with an exogenous non-traded sector). However, Cooley and Quadrini (2003) also show that the long-term welfare benefits of monetary cooperation dominate those associated with losing the ability to react optimally to shocks.

The world consists of two identical economies each populated with a continuum of agents of unit mass. Households supply labor, make deposits with financial intermediaries, and consume domestic and foreign goods, subject to a cash-in-advance constraint. In each country a unit mass of firms produce differentiated products using labor. Firms are heterogenous in productivity, incur a fixed cost of exporting, and borrow from financial intermediaries to fund working capital. Each government controls the money supply through lump-sum transfers. Consumption, output and the nominal price of the domestic output are denoted with h-subscripts. Foreign consumption, output and prices are denoted with f-subscripts. Asterisks denote foreign economy variables.

2.1. Households Intratemporal Consumption Decision

Households total consumption is a Cobb-Douglas composite of bundles of varieties of domestic and foreign goods.

$$C_t = \Theta \left(\int_0^1 c_{h,t}(a)^\rho \, da \right)^{\theta/\rho} \left(\int_{\mathsf{N}_t^\star} c_{f,t}(a^\star)^\rho \, da^\star \right)^{(1-\theta)/\rho} \tag{1}$$

where $c_{h,t}(a)$ is the consumption of a good produced by a firm with productivity a in the home economy, $c_{f,t}(a^\star)$ is the consumption of a good produced by a firm with productivity $a^\star$ in the foreign economy (of which $\mathsf{N}_t^\star$ are available to the home consumer), $\sigma = 1/(1-\rho) > 1$ is the elasticity of substitution between varieties of goods and the elasticity of substitution across the bundles of home and foreign goods is unity. The parameter θ measures openness to trade in varieties and is symmetric across the two economies, where $\Theta \equiv \theta^\theta (1-\theta)^{1-\theta}$. The consumer price index is defined as, $P_t \equiv \left(\int_0^1 p_{h,t}(a)^{1-\sigma} da \right)^{\theta/(1-\sigma)} \left(\int_{\mathsf{N}_t^\star} p_{f,t}(a^\star)^{1-\sigma} da^\star \right)^{(1-\theta)/(1-\sigma)}$.[4]

[4]With preferences of this form, household consumption is characterized by standard downward-sloped demand curves. For example, domestic consumption of a home good is, $c_{h,t}(a) = \theta \left(\frac{p_{h,t}(a)}{P_{h,t}} \right)^{-\sigma} \left(\frac{P_{h,t}}{P_t} \right)^{-1} C_t$. Normalizing the measure of domestically produced goods in each economy has no implications for the results.

2.2. Firm Pricing and Productivity Threshold

Each firm faces a financing constraint in that the current wage bill must be paid for with loans from financial intermediaries. Loans are made at the gross nominal interest rate, R_t, and are repaid at the end of the period. Firms produce without overhead costs and labor is the only factor of production. Exporting is costly because there are per-unit iceberg costs and labor-intensive fixed costs. For a firm with a linear technology and labor productivity a, profits from domestic sales can be written as, $\varphi_{h,t}(a) = (p_{h,t}(a) - W_t R_t / a)\, y_{h,t}(a)$. Profits from potential export sales are,

$$\varphi^{\star}_{h,t}(a) = \left(e_t p^{\star}_{h,t}(a) \frac{1}{\tau} - W_t R_t \frac{1}{a} \right) y^{\star}_{h,t}(a) - F W_t R_t \tag{2}$$

where $F \geq 0$ denotes the fixed cost associated with exporting and τ denotes the iceberg cost such that for $y^{\star}_{h,t}(a) = \gamma l^{\star}_{h,t}(a)$ units produced $\gamma l^{\star}_{h,t}(a) / \tau$ units are sold and generate revenue and e_t is the nominal exchange rate. The nominal interest rate appears both in the term capturing the costs of production and the term capturing fixed costs because firms are assumed to borrow the total wage bill.

The firm maximizes discounted total profits, $E_0 \sum_{t=0}^{\infty} (\beta^{t+1}/C_{t+1}P_{t+1})\, \varphi_t(a)$, where $\varphi_t(a) \equiv \varphi_{h,t}(a) + \varphi^{\star}_{h,t}(a)$, subject to the (home and foreign) demand for it's product and the goods market constraints, $y_{h,t}(a) = c_{h,t}(a)$ and $y^{\star}_{h,t}(a) = \tau c^{\star}_{h,t}(a)$. The optimal prices chosen by the home firm for the domestic and export market are, $p_{h,t}(a) = W_t R_t / \rho a$ and $p^{\star}_{h,t}(a) = (\tau / e_t)\, p_{h,t}(a)$, where ρ is the inverse monopoly markup.

Given the optimal pricing decisions of firms, there is a zero-profit, threshold level of productivity for exporting, denoted $a_{x,t} = \inf \left\{ a : \varphi^{\star}_{h,t}(a) > 0 \right\}$. The threshold level of productivity is characterized by, $r^{\star}_{h,t}(a) / \theta \geq F W_t R_t$, where, $r^{\star}_{h,t}(a)$ denotes home firm-level export revenue. When $F > 0$, this condition admits an explicit expression for $a_{x,t}$ in terms of endogenous variables,

$$a_{x,t} = \frac{\tau}{\rho}\left(\frac{\sigma F}{1-\theta}\right)^{1/(\sigma-1)}\left(\frac{W_t R_t}{e_t P_t^{\star} C_t^{\star}}\right)^{1/\rho}\frac{P_t^{\star}}{P_{h,t}^{\star}}C_t^{\star} \tag{3}$$

When $F = 0$, all firms export, and the threshold level of productivity is irrelevant.

2.3. Productivity Draws and Aggregation

A weighted-average productivity for all firms is defined as, $\mathsf{A} \equiv \left(\int_1^\infty a^{\sigma-1} g(a)\right)^{1/(\sigma-1)}$, where $g(a)$ is a probability density function. The weighted-average productivity for exporters is, $\mathsf{a}_t \equiv \left([1 - G(a_{x,t})]^{-1} \int_{a_{x,t}}^\infty a^{\sigma-1} dG(a)\right)^{1/(\theta-1)}$, where $1 - G(a_{x,t})$ is the probability of exporting, and $G(a)$ is the cumulative distribution function. I assume productivity is Pareto distributed, where $G(a) = 1 - a^{-\gamma}$, with $a > 1$. The shape parameter, γ, indexes the dispersion (of productivity), and characterizes firm heterogeneity. Since a is Pareto, I can solve for the weighted-average productivity of all firms as, $\mathsf{A} = \{\gamma / [\gamma - (\sigma - 1)]\}^{1/(\sigma-1)}$. In the same way, the weighted-average productivity for firms that export is, $\mathsf{a}_t = \mathsf{A} a_{x,t}$, so that a_t is proportional to the endogenous productivity cutoff defined by equation (3).

I aggregate firm-level variables using productivity averages. For example, consider the domestic currency price of the domestic product, $p_{h,t}(a)$, and define the average price as, $\mathsf{p}_{h,t} \equiv p_{h,t}(\mathsf{A})$. Using the price index, $P_{h,t} = \left(\int_0^1 p_{h,t}(a)^{1-\sigma} da\right)^{1/(1-\sigma)}$, where $p_{h,t}(a) = W_t R_t / \rho a$, we can write $\mathsf{p}_{h,t} = W_t R_t / \rho \mathsf{A}$, where A is consistent with the definition introduced above. This average price is linked to the consumer price, $P_{h,t}$. In this case, because there are a measure one of firms, $P_{h,t} = \mathsf{p}_{h,t}$. The same aggregation can be applied to all firm-level variables.

2.4. Household Financial Deposits and Labor Supply

Households intertemporal utility is $\sum_{t=0}^\infty \beta^t u(C_t, L_t)$, where L_t is the total supply of labor. Utility from consumption is increasing, concave, and continuously differentiable and disutility of work is increasing, convex, and continuously differentiable. At the beginning of a period, households deposit cash with domestic financial intermediaries. Any remaining cash is used for (total) consumption, subject to the following cash-in-advance constraint,

$$P_t C_t \leq W_t L_t + M_t - D_t \tag{4}$$

where $D_t > M_t$ are household deposits of cash with intermediaries and $W_t L_t$ is nominal labor income. The accumulation of cash (i.e., the cash the consumer has at the end-of-period t/beginning-of-period $t+1$) is,

$$M_{t+1} \leq W_t L_t + D_t i_t + \varphi_t + \zeta_t - P_t C_t + M_t \tag{5}$$

where ζ_t are profits of financial intermediaries and $i_t = R_t - 1 > 0$ is the net nominal interest rate. Households maximize lifetime utility subject to these two constraints and the first-order conditions imply the following.

$$w_t u_C (C_t, L_t) + u_L (C_t, L_t) = 0 \tag{6}$$

and

$$E_{t-1} \left\{ \frac{u_C (C_t, L_t)}{P_t} - \beta R_t \left[\frac{u_C (C_{t+1}, L_{t+1})}{P_{t+1}} \right] \right\} = 0 \tag{7}$$

where $w_t \equiv W_t / P_t$ is the real wage and subscripts denote the derivative of the utility function with respect to that variable. The first expression is a condition for the labor-leisure trade-off. The second expression is an Euler equation in consumption. Household savings are made entirely through the domestic financial intermediary and the expectations term, E_{t-1}, appears in the Euler equation because household deposits with financial intermediaries are predetermined.

2.5. Equilibrium

Financial intermediaries receive cash from households and from the government, which total $D_t + T_t$. They make loans to firms at the net interest rate. At the end of the period, intermediaries pay interest on loans back to households, so the total amount households receive at the end of the period is, $R_t(T_t + D_t)$, and the profit of financial intermediaries is, $\zeta_t = R_t T_t$. Equilibrium in the financial sector is such that, $W_t L_t = D_t + T_t$, and when the government has access to lump-sum transfers and taxes, $T_t = gM_t$, where $1 + g \equiv M_{t+1}/M_t$ is the rate of money growth.

Resource use (labor) in the economy can characterized as,

$$\mathsf{A}L_t = \theta q_t^{1-\theta} C_t + \tau (1-\theta) \left(\frac{\mathsf{A}}{\mathsf{a}_t}\right)^{1+\frac{\gamma}{1-\sigma}} (q_t^\star)^\theta C_t^\star + \mathsf{A}F \left(\frac{\mathsf{A}}{\mathsf{a}_t}\right)^\gamma \tag{8}$$

where the first two terms on the right-hand side of equation (8) capture the use of labor for production and $F(\mathsf{a}_t/\mathsf{A})^\gamma$ is the use of labor by exporting firms to cover fixed costs. The variables $q_t \equiv P_{f,t}/P_{h,t}$ and $q_t^\star \equiv P_{f,t}^\star / P_{h,t}^\star$ are relative prices.

There is no international trade in financial assets (financial autarky) and balanced trade holds each period. Balanced trade is consistent with,

$$C_t / C_t^\star = e_t P_t^\star / P_t \tag{9}$$

where $e_t P_t^\star / P_t$ is the consumer-based real exchange rate.

3. Model Solution

In this section I characterize the model solution. Since I focus on the systematic inflation generated from interaction between countries, I write the households consumption Euler equation as $\pi = \beta R - 1$. This states that higher inflation is associated with higher nominal interest rates. Eliminating wages in the remaining conditions above generates conditions that solve for $\{C, L, q, \mathsf{a}, R\}$ and their foreign counterparts as a function of money growth. In table 1, I present the model equations for the home economy with the understanding that there are four additional equations describing resources, the labor market, a cash-to-loans ratio, and productivity, for the foreign economy.

===== **Table 1 Here** =====

The variable $d \equiv D/M$ is the stock of financial assets held by households in domestic financial intermediaries and $\omega \equiv \tau \left(\frac{\sigma F}{1-\theta}\right)^{1/(\sigma-1)} > 0$ is a composite parameter.

We can use the conditions in table 1 to understand how the distortions present in each economy influence the government's non-cooperative policy decision. Because the stock of deposits is decided upon at the end of the period - and households wait until the end of the following period before changing their deposits - monetary policy generates a liquidity effect. If the economy were closed to trade, this liquidity channel would be the only mechanism through which the nominal interest rate affected the real sector of the economy (to see this, set $q = \mathsf{A} = \mathsf{a} = 1$ in the first three equations and ignore the final three). In a closed economy, it is optimal for the government to lower interest rates, reduce the monetary distortion, and raise output to the perfectly competitive level. However, this is not feasible because of the zero lower bound on interest rates. Thus, optimal policy sets the interest rate at zero (with deflation at the rate of time preference) consistent with the Friedman rule.

When there is trade in varieties, monetary policy affects the macroeconomy through changes in relative prices, q and $q^{\star}$. For example, a monetary contraction reduces the interest rate and induces an appreciation of the domestic currency. This generates a reduction in the level of domestic activity, controlling for the negative liquidity effect. Other open economy models, such as Corsetti and Pesenti (2001) and Cooley and

Quadrini (2003), also emphasize this channel of monetary transmission, and here it is a source of policy competition (this result can be recovered from table 1, now by including the final two equations, setting $C = C^{\star}$ and $(q/q^{\star})^{1/2} = \tau$, whilst maintaining $\mathsf{A} = \mathsf{a} = 1$). To take advantage of favorable movements in the terms of trade countries need to reduce own output. This generates a trade-off between manipulating the terms of trade and reducing the monetary distortion which depends on the size of the monopoly distortion.

The terms of trade channel just described generates one conflict of interest between the two countries. However, this conflict is not the only basis for policy competition because monetary policy also affects the allocation of resources and the extent of economic integration. In this case, a monetary contraction raises the costs of exporting, and since it is more expensive to export, less firms do so. Because only the most productive firms export, the firms that leave the export market are, by definition, those with lower levels of productivity. Thus, the average level of productivity of firms that exports must rise (the average level of productivity of firms across the economy is unaltered) and resources are re-allocated to the remaining exporting firms. In my model, this source of policy competition generates additional inflation with quantitatively important welfare consequences.

4. Optimal Monetary Policy

In this section I derive the constraints faced by the policy maker in terms of the nominal interest rate, which is the policy variable.[5] I also define optimal monetary policy when each government acts independently and the welfare loss from not cooperating.

[5] In the Appendix, I show for a given stock of deposits, that the specification of the monetary policy instrument in terms of money growth rates or interest rates is equivalent. After this, I derive the constraints presented in this section.

4.1. Policy Constraints

I focus on the home economy and start by deriving a constraint for the labor market. The home country's total supply of labor can be expressed in terms of consumption, for a given policy, as,

$$(\rho + \epsilon) C u_C (C, L) + R L u_L (C, L) = 0 \tag{10}$$

The term $\epsilon \equiv (1 - \theta) [1 - \rho (1 + 1/\gamma)]$ in equation (10) results entirely from firm-level heterogeneity, where $\gamma > \sigma > 1$ indexes the dispersion of productivity, and $1 < \rho = (\sigma - 1)/\sigma < 1$ is the inverse monopoly markup. There is no trade in varieties when $\theta = 1$, and then $\epsilon = 0$.

Given the labor market constraint, I express total consumption in terms of the total labor supplied in each economy, L and $L^\star$. Home consumption is a weighted-average of home and foreign labor,

$$C = \chi L^\theta (L^\star)^{(1-\theta)\eta} \tag{11}$$

where $\chi > 0$ and $\eta > 1$. Again, both of these parameters result from firm-level heterogeneity. The parameter χ is a function of iceberg and fixed costs of exporting and $\eta \equiv 1/\mu - (1 - 1/\rho)$, where $\mu = \gamma/(\gamma - 1) \geq 1$ is the arithmetic mean of the Pareto distribution. Recall, that preferences over total consumption (see equation (1)) are specified as in Dixit and Stiglitz (1974). In this case, the parameter σ denotes the elasticity of intratemporal substitution (i.e., across varieties) and $1/\rho - 1$ is the marginal utility gain from spreading a given amount of consumption on a basket with an additional variety in a symmetric equilibrium. We can therefore think of $\eta > 1$ as capturing heterogeneity-adjusted love-of-variety.

4.2. Non-Cooperative Monetary Policy

When monetary policy is set non-cooperatively, the problem for the home government is to pick $R \geq 1$ to maximize $u(C, L)$, subject to (10), (11), and their foreign counterparts, taking $R^{\star}$ as given. Similarly, the foreign government maximizes $u(C^{\star}, L^{\star})$, picking $R^{\star} \geq 1$, subject to it's constraints, taking R as given. Given that home and foreign interest rates are independent, we already know that the reaction function of each government is independent of the other government's policy variable. Since the economies are identical, we also know $R = R^{\star}$, in equilibrium. From here on, I denote the outcome of non-cooperative policy by R.

4.3. Welfare Loss from Non-Cooperation

When governments cooperate, I assume a supranational agency controls both policy instruments and maximizes a weighted average of home and foreign consumers utility. The policy problem is to pick interest rates to maximize $(1/2)\, u(C, L) + (1/2)\, u(C^{\star}, L^{\star})$, subject to the same constraints as the non-cooperative case. Under cooperation, the supra-national agency acts as if it were running a closed economy and attempts to push the interest rate down, eliminating the monetary and monopoly distortions. However, given the zero lower bound on the nominal interest rate, the government cannot eliminate the monopoly distortion in an equilibrium with commitment. Because cooperation removes the channels that provide an incentive for each government to engage in policy competition, the Friedman rule is optimal.

The potential welfare loss from not cooperating - denoted by $\mathcal{L}$ - is defined by the additional consumption required to make individuals equally well-off under cooperative or non-cooperative policy. In particular, $\mathcal{L}$ is the increase in steady-state consumption an individual would require when policy is non-cooperative, to be as well-off as under the Friedman rule. The welfare loss from non-cooperation is implicitly defined by,

$$u\left(\left(1 + \mathcal{L}\right) C\left(R\right), L\left(R\right)\right) = u\left(C\left(1\right), L\left(1\right)\right) \tag{12}$$

where $C(\cdot)$ and $L(\cdot)$ are the associated allocations of consumption and labor in each regime, i.e., R or 1.

5. Results

In this section I discuss the role of resource allocation and endogenous economic integration in generating inflation and welfare losses from non-cooperative policy. I then calibrate the model and present a quantitative analysis of the welfare loss from non-cooperation.

5.1. Economic Integration and Firm-Level Heterogeneity

I first adopt a simple specification for preferences that allows an analytical solution to the government's policy problem. I assume the utility function of the household has the following form: $u(C, L) = \ln C + \ln(1 - L)$. This implies the intertemporal substitution of consumption and the Frisch elasticity of labor supply are both equal to one. I also assume $\theta = 1/2$, which implies $C^R = \left(1/\mathsf{a}^R\right)^{\left(1+\frac{\gamma}{1-\sigma}\right)/2}$, so that relative consumption is solely a function of exporter productivity levels. Under these conditions, there is always policy competition between countries and inflation is above the Friedman rule. Home inflation can be written as,

$$\pi = \beta\left(1 + \frac{\rho}{\mu}\right) - 1 \tag{13}$$

There are two elements to (13): the inverse monopoly markup, $0 < \rho < 1$, and the mean of the Pareto distribution, $\mu = \gamma/(\gamma - 1) \geq 1$. Recall that the parameter γ indexes the dispersion of productivity, and as γ rises, firm-level productivity is less dispersed, and the mean of the distribution approaches one.[6] Thus, higher inflation

[6] We can also relate this parameter to the empirical standard deviation of sales (output), which in my model is given by $\left(\frac{1}{\gamma+1-\sigma}\right)$. I use this definition to calibrate the model. From a qualitative perspective, both terms measure the dispersion of productivity and fall with γ.

is consistent with lower average productivity/less dispersed productivity at the firm level, as measured by μ or A. The explanation for this result derives from the fraction of exporting firms in each economy. Less productive economies have a greater number (of smaller) exporters. With a higher fraction of exporters, there is a greater incentive for the government to manipulate relative prices, and more scope to use policy to re-allocate resources to the most productive firms.

It is also possible to understand this result by relating it to the case when economic integration between countries is given. Even in the presence on non-zero fixed costs, for a sufficiently high γ, all firms export. However, one cannot simply set $\mu = 1$ because this case also requires $\mathsf{a} = a_x^\star \to 1$ such that the threshold productivity for an individual firm to export approaches the minimum draw from the Pareto distribution. I therefore impose $\mathsf{A} = \mathsf{a} = 1$. Inflation can then be written as $\pi = \beta 2\rho - 1$. This condition shows why endogenous economic integration and resource allocation matter. For certain configurations (in this particular case, when $0 < \rho < 1/2$), the Friedman rule is optimal because the trade-off the government faces when setting policy is determined by the extent of competition in the product market. When policy affects the allocation of resources across firms, inflation is always above the Friedman rule.

I now analyze how policy competition feeds into the welfare losses arising from non-cooperation. Using equations (10)-(13),

$$\mathcal{L} = \left(\frac{3}{3+\frac{\rho}{\mu}}\right)\left[\left(1+\frac{\rho}{\mu}\right)\left(\frac{3}{3+\frac{\rho}{\mu}}\right)\right]^{(1+\eta)/2} - 1 \tag{14}$$

The first term in (14) captures the differences in labor supplied across regimes (i.e., with cooperative and non-cooperative policies). The second term is the consumption difference across regimes. Notice that the consumption difference contains a heterogeneity term in the exponent - specifically $\eta > 1$ - and the long-run welfare losses are driven by international economic integration for two reasons. First, long-run inflation, which affects both consumption and labor supplied, is higher. Second, households access a varying subset of foreign products. The second loss in welfare reflects the love-of-variety by households, adjusted for the fact that traded varieties are supplied by firms that are heterogeneous in productivity.

To isolate this additional welfare effect, I decompose the loss from non-cooperation into two parts by re-writing (14) as, $1 + \mathcal{L} = R^{(1+\eta)/2} \left[3/\left(2+R\right)\right]^{1+(1+\eta)/2}$. The first part of this new expression derives from the negative impact of higher interest rates on welfare. Recall that a lower μ means more firms export, and from (13), this leads to higher interest rates ($R = (1+\pi)/\beta$) and greater losses from non-cooperation. The second part results from the effect on consumption, for a given policy. Recall that $\eta = 1/\mu - (1 - 1/\rho)$. Holding the interest rate constant, $\mathcal{L}$ falls with μ. Thus, changing heterogeneity has complementary effects. A lower μ is consistent with higher long-term inflation when countries set policy independently, and for a given rate of inflation, lower levels of μ generate greater welfare losses from non-cooperative policy.

The mechanism that generates inflation in this model works alongside a more standard one. For a given measure of traded goods, each government will attempt to inflate, and manipulate the terms of trade. Since this represents an attempt to push output down, there is a reduction in the intensive margin of trade. With firm-level heterogeneity, policy also works along the extensive margin of trade (i.e. changes in the fraction of firms that export, for a given export volume per-firm). This captures the extent of international economic integration. Optimal non-cooperative policy dictates that, in addition to reducing own output, each country should also reduce the proportion of firms that export. This dual role for policy in affecting the margins of trade is the reason there are direct and indirect long-run welfare implications of inflation.

5.2. Calibration and Quantitative Analysis

In this section I calibrate the model and quantify the welfare losses from non-cooperation. I first set the model parameters to match some simple stylized facts assuming that countries cooperate. I then determine the optimal policy when countries act independently and calculate the allocations associated with this policy. Finally, I change the degree of firm-level heterogeneity to determine how this affects policy competition and the associated long-term welfare loss. Changing firm-level heterogeneity affects the allocations when there is monetary cooperation, although it does not change the policy decision, and it changes optimal policy when countries act independently.

I also generalize the utility function used above in two ways. First, I assume the parameter $\xi > 0$ determines whether goods are substitutes or complements in utility. In my model, two goods are substitutes - i.e., the marginal utility of one good decreases with the consumption of the other good - when the elasticity of intertemporal substitution is less than the elasticity of intratemporal substitution. Because the intertemporal elasticity is $1/\xi$ and the intratemporal elasticity is 1, home and foreign goods are substitutes when $\xi > 1$.[7] Second, I allow $\psi > 1$ to determine the weight of leisure in utility so that I can match the model to hours worked.

I calibrate the model so a period corresponds to one quarter and set $\beta = 0.995$. I assume a price markup for firms of 30% over marginal costs and set $\sigma = 4.33$. To match the model with firm-level data I assume the standard deviation of output is 1.67, consistent with Bernard *et al.* (2003). In my model, this statistic is given by

[7] In my model, the easiest way to understand why the substitutability of goods in utility matters is by noticing that when $\xi = 1$, the impact of changing policy on exporting is independent of changes in consumption. This is a type of 'no international spillover' result: home policy affects foreign consumption, but since foreign consumption does not affect the fraction of foreign firms that export, there are no implications from policy.

$1/(\gamma - \sigma + 1)$, and given the firms price markup, this further implies $\mu = 1.34$ and $\mathsf{A} = 1.76$. I also assume per-unit trade cost of approximately 16%, which implies setting $\tau = 1.2$, that consumers allocate 25% of their consumption expenditure to traded goods originating from abroad, which is a measure of home-bias in traded consumption baskets, and that home and foreign goods are mild complements in utility, with $\xi = 0.9$. Finally, I calibrate the fixed export cost so the proportion of exporting plants matches the figure of 21% reported in Bernard *et al.* (2003), which implies $F = 0.016$, and calibrate the weight placed on leisure in utility so individuals spend 30% of their time endowment working, which implies $\psi = 1.66$.

In table 2, I present the welfare loss from non-cooperation along with the annual rate of inflation and the exporter productivity premium for differing degrees of firm-level heterogeneity, as measured by $1/(\gamma - \sigma + 1)$.

===== **Table 2 Here** =====

The welfare loss from non-cooperation in the benchmark case is 2.6% of annual steady state consumption. Table 2 also shows the welfare loss from non-cooperation (inflation) rises (is higher) the more homogenous are firms. Intuitively this seems surprising, because higher interest rates and inflation reduce the proportion of firms that export. However, there are two opposing effects on the exporting decision of firms when productivity dispersion changes. One is generated through induced policy changes, which itself depends on the economic integration between economies. The second effect depends on the impact of changes in productivity dispersion, independent of policy. Higher inflation with more exporters (a lower exporter premium) is explained by the dominant role of productivity dispersion on the decision of firms to export.

When all varieties are traded, and the allocation of resources is fixed, the long-run welfare loss associated with non-cooperative policy (not reported in table 2) is 1.51% of annual consumption. This is less than when policy affects the allocation of resources and economic integration is endogenous in the benchmark case and also less than when the exporter productivity premium is high and very few firms export. Consider the final column/row of table 2, which shows how much more productive exporters are compared to the economy-wide average in the most extreme case considered. The exporter productivity premium is inversely related to the fraction of firms that export and with a few highly productive export firms policy competition is less aggressive for the reasons explained above. Nevertheless, additional policy competition still generates a greater welfare loss than with fixed resource usage.

The quantitative results in this section can also be considered more broadly in the context of the literature on the gains from international monetary coordination, which assumes international economic integration is given. Cooley and Quadrini (2003), for example, argue the welfare loss from non-cooperation when governments commit to policy is less than one percent of annual steady state consumption.[8] In the benchmark case, where the standard deviation of firms sales is set at 1.67, the welfare loss from non-cooperation in my model is over three and a half times greater (and proportionally higher than the difference in inflation). One conclusion from this is that when the allocation of resources across exporting and non-exporting firms is endogenous the adverse welfare implications of non-cooperative policy are quantitatively important.

5. Conclusion

This paper studies optimal monetary policy in a two country general equilibrium model

[8]Absent endogenous economic integration, this figure is still half that generated by my model. This is a result of endogenous labor supply.

where international economic integration is endogenised through firm-level heterogeneity and monopolistic competition. Economic integration between countries is a source of policy competition, generating higher long-run inflation, and increased gains from monetary cooperation. The gains from cooperating are greater in economies where many firms export because resources use is not concentrated among the most productive firms. From a quantitative perspective, the benchmark welfare loss from non-cooperation is around two and a half percent of annual steady state consumption.

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Table 1: Model Equations for Home Economy

Resources	$\mathsf{A}L = Cq^{1-\theta} + \mathsf{A}F\left(\mathsf{A}/\mathsf{a}\right)^{\gamma}$
Labor Market	$u_C\left(\cdot\right)\rho\mathsf{A}q^{\theta-1} + u_L\left(\cdot\right)R = 0$
Cash-to-Loans	$u_C\left(\cdot\right)C\left(d+\mu\right) + u_L\left(\cdot\right)L\left(1+\mu\right) = 0$
Productivity	$\mathsf{a} + \left(\mathsf{A}\omega/\rho\right)\left[u_L\left(\cdot\right)R/u_C\left(\cdot\right)C\right]^{1/\rho} q^{\star\theta}C^{\star} = 0$
Relative Prices	$\left(q/q^{\star}\right)^{1/2} = \tau\left(\mathsf{A}/\mathsf{a}^{W}\right)^{1+\frac{\gamma}{1-\sigma}}$
Balanced Trade	$C/C^{\star} = \left(\mathsf{a}^{\star}/\mathsf{a}\right)^{\left(1+\frac{\gamma}{1-\sigma}\right)\left(1-\theta\right)}\left[\left(\tau/q\right)\left(\mathsf{A}/\mathsf{a}^{\star}\right)^{1+\frac{\gamma}{1-\sigma}}\right]^{1-2\theta}$

Table 2: Welfare Loss without Monetary Cooperation

Firm Heterogeneity	.5	1	1.67	2	5	10
Welfare Loss	4.41	3.21	2.60	2.43	1.91	1.72
Inflation	17.52	12.92	10.47	9.79	7.52	6.69
Productivity Premium	16.41	36.75	52.23	60.01	109.75	159.41

Appendix

Here I show that using the nominal interest rate or money growth rate are equivalent monetary policies. I also solve for consumption and labor supplied as a function of home and foreign nominal interest rates. I focus on the home economy.

A.1. Interest Rate Policy

I first use $wu_C(C,L)+u_L(C,L)=0$ and it's foreign counterpart to write the equations in table 1 in terms of wages. Then define (for some variable, x) $x^R \equiv x/x^\star$ as 'relative' x, and $x^W \equiv (xx^\star)^{1/2}$ as 'world' x. Using these definitions, the equations that determine average productivity imply,

$$\mathsf{a}^R = \left[\frac{\left(w^R R^R\right)^{\frac{\theta-\sigma(2\theta-1)}{1-\theta}}}{\left(C^R\right)^{2\sigma-1}}\right]^{1/(\sigma-1)} \quad ; \quad \mathsf{a}^W = \lambda_1 \left[\frac{\left(w^W R^W\right)^{\frac{\sigma-\theta}{1-\theta}}}{C^W}\right]^{1/(\sigma-1)} \tag{A1}$$

where $\lambda_1 \equiv (\mathsf{A}\omega/\rho)\,(1/\rho\mathsf{A})^{\theta/(1-\theta)}$. Next, using the ratio of labor demands and balanced trade, I solve for productivity levels and home consumption as functions of the relative and world real wage and nominal interest rate. For productivity, where $\mathsf{a} = \mathsf{a}^W\left(\mathsf{a}^R\right)^{1/2}$,

$$\mathsf{a}^R = \left(w^R R^R\right)^{1/\left[\gamma\left(\frac{1-2\sigma}{1-\sigma}\right)-1\right](1-\theta)} \quad ; \quad \mathsf{a}^W = \lambda_2\left(w^W R^W\right)^{1/\left(1+\frac{\gamma}{1-\sigma}\right)(1-\theta)} \tag{A2}$$

where $\lambda_2 \equiv \mathsf{A}\left[\tau\,(\rho\mathsf{A})^{1/(\theta-1)}\right]^{1/\left(1+\frac{\gamma}{1-\sigma}\right)}$. The two equations in (A2) along with (A1) also determine C^R and C^W as a function of real wages and nominal interest rates. Taking the ratio of these conditions and plugging the solution (for a/C) into the cash-to-loans ratio and resource constraint there is a unique relationship between the domestic growth rate of money and the domestic interest rate. In this case, choosing the nominal interest rate or money growth rate are equivalent policies ($R^\star$ and $g^\star$ are equivalent policies for the foreign government), and I can treat R as the choice variable for the home government with g determined residually. This result is independent of the specification of utility.

A.2. Constraints on Monetary Policy

I now solve for home consumption and labor supplied as functions of home and foreign interest rates. Taking the ratios and weighted averages of the solution for a/C and it's foreign counterpart, and eliminating wages by using the labor leisure trade-off I generate equation (10) in the text. If I eliminate the terms $w^R R^R$ and $w^W R^W$ in the solution for consumption, I find,

$$C^R = \left(L^R\right)^{\left\{\left(1+\frac{\gamma}{1-\sigma}\right)+(1-2\theta)\left[\left(1+\frac{\gamma}{1-\sigma}\right)-2\gamma\right]\right\}/2\gamma} \quad ; \quad C^W = \chi\left(L^W\right)^{1-(1-\theta)\left(1+\frac{\gamma}{1-\sigma}\right)/\gamma} \tag{A3}$$

where $\chi \equiv \varkappa\left[\varkappa\left(\epsilon+\rho\right)\right]^{\left(\frac{1-\theta}{\gamma}\right)\left(1+\frac{\gamma}{1-\sigma}\right)-1}$ and $\varkappa \equiv \varkappa\left(\lambda_1, \lambda_2\right)$. I convert the expressions in (A3) to solve for home consumption using $C = C^W\left(C^R\right)^{1/2}$. Doing so generates equation (11) in the main text.