Trend Inflation, Price Rigidity, and International Trade: Inflation as a Long-run Source of Comparative Advantage and Welfare Improvement

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Abstract

This paper introduces the Calvo-style sticky price model with trend inflation into the classical two-country Ricardian and Ricardo-Viner trade models, and provides novel implications of the interactions between the nominal- and real-side in the long-run steady state equilibrium. First, the pattern of trade relates to the industry-level price and productivity, and the industry-level price and productivity in turn depend on the country's inflation rate and the degree of price stickiness of each industry. As a result, the monetary policy has different impacts across industries, and hence it may act as a trade policy. Second, the inflation rate affects the terms of trade through changing the productivity. Such a manipulation of the terms of trade generates the welfare gain of the country. The optimal inflation rate in the open-economy is positive under some parameter values, contrary to the standard closed-economy or small-open sticky price models which implies that the optimal inflation rate is zero. Even if not positive, the welfare loss of deviating from zero inflation is always lower under two-country models than one under the closed-economy or small-open models.

Keywords: Ricardian trade model; Sticky price; Optimal inflation rate; Trend inflation; Immizerising growth; Ricardo-Viner trade model; Specific factor trade model.
JEL Codes: E31, E52, F11, F13, F41, F42.

1 Introduction

Trade models usually abstract the nominal-side.[1] A reason is that international trade models consider the long-run real allocations, and in the long-run the nominal-side is assumed to play no essential role. However, recent monetary studies theoretically show that the nominal-side can have a long-run (steady state) real consequence under trend inflation (e.g., Damjanovic and Nolan, 2010; Ascari and Sbordone, 2014). Meanwhile, motivated by recent convention that many central banks set target inflation rates

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[1]For example, in a graduate-level textbook, Feenstra (2016), the term "nominal" appears 20 times, but the usage is exclusively for explaining empirical variables.

to be positive, monetary studies analyze the consequence of trend inflation on economic welfare using various versions of sticky price models with trend inflation (e.g., King and Wolman, 1999; Ascari, 2004; Schmitt-Grohé and Uribe, 2007, 2011; Ascari and Ropele, 2007; Coibion et al., 2012; Ascari and Sbordone, 2014). These studies basically conclude that zero-inflation rate maximizes welfare. However, these authors focus on single-good closed-economy settings, and the long-run consequence of trend inflation in an open-economy is yet to be analyzed.

This paper introduces a stylized model of nominal rigidity with trend inflation to the classical Ricardian and Ricardo-Viner international trade models, and analyzes the long-run stationary state properties. The long-run analysis follows the tradition of trade studies, which consider a stationary (static) situation. In addition, the long-run theoretical analysis is practically important to understand the consequence of the current convention of positive target and actual inflation rate across countries.

The model indicates several novel implications of the interactions between the nominal- and real-side. First, the magnitude of price rigidity and the inflation rate affect the pattern of trade. As a result, the monetary policy has different impacts across industries, and hence it may act as a trade policy. Thus, the model provides an example of a break of the neo-classical dichotomy in international trade models. Second, under some parameter values, the optimal inflation rate in the open-economy is positive, contrary to the standard closed-economy or small-open sticky price models which implies that the optimal inflation rate is zero. The inflation rate affects the terms of trade through changing the relative effective productivity across industries. Such a manipulation of the terms of trade generates the welfare gain of the country. When this gains from the terms of trade is large enough to offset the loss of the production capacity reduction, non-zero inflation leads to the welfare gain. In general, the welfare loss of deviating from zero inflation is always lower under two-country models than one under the closed-economy or small-open models.

The rest of the introduction explains the main idea of the paper and the contributions to the literature. Section 2 introduces the model. Section 3 presents the results. Section 4 concludes.

1.1 Mechanism

The baseline model builds on the canonical Calvo-style sticky price model (Calvo, 1983; Yun, 1996) with trend inflation (Schmitt-Grohé and Uribe, 2007, 2011; Ascari and Sbordone, 2014) and the classical two-country two-good Ricardian model. Labor is the fundamental production factor. Nontradeable intermediate goods are produced using a linear-in-labor technology (constant-returns-to-scale; CRS) in the baseline setting, and these intermediate goods are used for producing tradeable final goods. Intermediate producers produce differentiated intermediate goods, so that intermediate goods markets are monopolistically competitive. Each intermediate producer sets its selling price subject to the probabilistic opportunity of a price adjustment (standard "Calvo" friction). Accordingly, price is rigid in the intermediate goods market, which is the input-side of the final goods, rather than the output-side of the final goods.[2] Under

[2]In standard monetary open-economy macro models such as Obstfeld and Rogoff (1995), Devereux and Engel (2003) and Corsetti et al. (2011), final good producers set their output prices. These authors analyze the short-run dynamics of the exchange rate influenced by price setting behavior of the tradeable final goods producers ("producer's currency pricing" or "local currency pricing"). The reasons why this standard specification is not adapted here are as follows. First, empirical trade studies show that exporters are rare, and that domestic sales are larger than foreign sales even for exporters (e.g.,

autarky, an industry-level aggregation result holds, which is the same aggregation result as in a model with the price rigidity in the final good sector. In the current setting, the same aggregation result holds in the open-economy equilibrium.

After the industry-level aggregation, the final good production is expressed as a product of the labor and the effective productivity term, and the effective productivity term depends on the nominal-side parameters. Labor is the total number of workers in the industry. The effective labor productivity consists of two terms: the exogenous productivity, and the real resource costs. The exogenous productivity is exogenously given, and is common within industry. The real resource costs come from the price dispersion across symmetric intermediate goods due to the price rigidity and inflation. In this sense, the real resource costs depend on the nominal-side parameters. The industry-level price of the final good depends on this effective labor productivity and the markup. The markup (i.e., the ratio of output price to the the marginal cost) fundamentally stems from the monopolistic competition in the input market. The effective markup depends not only on the elasticity of substitution among input variety but also on the nominal-side parameters owing to the price dispersion within and across industries.

In the costless trade equilibrium, the relative price under autarky determines the patten of specialization as in the standard Ricardian model, and the relative price depends on exogenous productivity, the resource cost, and the markup. Consequently, the pattern of trade depends on the nominal-side parameters: inflation rate and the probabilities of price change. More precisely, since low rigidity and low (close to zero) inflation rate lead to high industry-level productivity, the industry is more likely to have a comparative advantage, holding other factors constant. As a result, the monetary policy controlling the aggregate inflation rate has different impacts across industries, and hence it may act as a trade policy even in the long-run. This long-run implication contrasts with and complements the standard argument for the short-run effects, which explains the monetary policy acts as a trade policy through changing the nominal exchange rate (e.g., Corsetti et al., 2011).

The optimal inflation rate in the open-economy is then positive (or negative) under some parameter values, contrary to the standard closed-economy sticky price models which imply that the optimal inflation rate is zero. In the analysis, welfare is measured by the steady state utility of the household (King and Wolman, 1999; Ascari, 2004). The channel induces non-zero inflation to be optimal is the immiserizing growth through manipulating the terms of trade, and hence sacrifices the welfare of the trade partner.[3]

In the standard single-good closed-economy sticky price models, King and Wolman (1999) show that the optimal inflation rate calls for managing two distortions: the markup distortion and price distortion.[4] Monopolistic competition leads to the markup distortion. When inflation rate is high, price setters choose high markup. Meanwhile, the expected average markup during the non-adjusting period is low. As a

Bernard and Jensen, 1999). Second, empirical price studies (see reference in Klenow and Malin, 2011) show that price rigidity is prevalent both in consumer price index data and producer price index data. Given these empirical facts, the implications of the price rigidity in the domestic intermediate input market is worth to be analyzed. Third, theoretically, the current specification can abstract a complicated cross-country price setting behavior.

[3]Under certain parameters, the inflation setting behavior resembles to the short-run competitive devaluation problem (c.f., Corsetti et al., 2011) and the strategic tariff problem (c.f., Bagwell and Staiger, 1999). The strategic interaction of inflation settings is not examined in this paper, but is an important future research topic.

[4]King and Wolman (1999) use a staggered price model rather than the Calvo model, but the difference is not essential in the steady state.

result, average markup is the lowest under a mild inflation, which minimizes the loss from the markup distortion. King and Wolman (1999) also show that under the standard parameters the welfare gain of reducing the markup distortion is quantitatively small. Partly due to this quantitatively minor role, some researchers drop the markup distortion by including distortion-corrective tax/subsidy, and focus on the price distortion (see discussion by Benigno and Woodford, 2005). The price distortion is associated with the price dispersion among the differentiated products. Zero-inflation rate eliminates the resource loss of this dispersion, and non-zero inflation rate effectively reduces industry-level productivity if the industry's price is rigid (Damjanovic and Nolan, 2010). In single-good closed-economy models, a tiny-positive inflation maximizes the welfare with two distortions, and zero-inflation maximizes the welfare if the markup distortion is already adjusted.

This productivity reduction through the price distortion under the positive (or negative) inflation presents even in the open-economy equilibrium, but in two-country open-economy settings, a productivity loss is not necessarily leads to a lower welfare. Instead, in some cases, the productivity loss improves welfare of the country. The reverse version of this mechanism is classically known as the immiserizing growth (Johnson, 1955; Bhagwati, 1958). That is, technological improvement may decrease the welfare of the country because the expansion of exporting industry leads to a deterioration of the terms of trade (i.e., the relative price of exports in terms of imports). Thanks to this mechanism, under a certain set of parameters, non-zero inflation effectively decreases the productivity of the exporting industry, improves the terms of trade, and then improves the welfare of the country. This channel of the welfare improvement is enacted by either deflation or inflation, but the productivity reduction is more sensitive to inflation than deflation. In this sense, inflation case is more important.

In the extension, the intermediate production still depends only on labor but now exhibits the decreasing-returns-to-scale (DRS). The industry-level aggregation of production still holds; the real resource cost term appears as the additional term in the aggregate production function. The expression of the relative price differs from the CRS case. The relative price of two goods under autarky now depends on the size of the production of each sector. The corresponding trade model is the Ricardo-Viner (as also known as the specific factors) model. Both of the two countries produce both of the two goods, and they exchange one of the goods each other. The basic implications obtained in the CRS setting carry over in this extension. First, the pattern of trade depends on the inflation rate and the probabilities of price change, among other parameters. Second, under a certain condition, the terms of trade improves as the inflation rate of the home country deviates from one. Third, the terms of trade generally attenuates the loss of the resource cost, and in some cases, inflation improves the welfare of the home country. In addition, this Ricardo-Viner model provides a simple formula of characterizing the welfare impact, based on country's import share, the elasticity of the terms of trade with respect to the inflation rate, and the elasticity of the resource cost with respect to the inflation rate.

1.2 Literature

This paper contributes to two strands of the literature: monetary studies considering the optimal inflation rate, and trade studies considering determinants of comparative advantage and the effects of policies on the pattern of trade.

First, the paper relies on the literature examining the optimal inflation using sticky price with trend inflation (Calvo, 1983; Yun, 1996, 2005; Ascari, 2004; Schmitt-Grohé and Uribe, 2007, 2011; Ascari and Ropele, 2007; Damjanovic and Nolan, 2010; Ascari and Ropele, 2009; Ascari et al., 2011; Coibion et al., 2012; Ascari and Sbordone, 2014, among many). By dropping the cost of intrinsically useless money holdings (which implies that deflation is optimal: the Friedman rule), price stabilization through zero-inflation rate is optimal in the long-run. In the short-run, the initial price dispersion induces a slight negative rate to be optimal (Yun, 1996; Damjanovic and Nolan, 2010), whereas a possibility of hitting to the zero-lower bound of the nominal interest rate implies that a slight positive rate to be optimal (Schmitt-Grohé and Uribe, 2011; Coibion et al., 2012).

Many researchers also examine the price rigidity and the optimal inflation rate in the multi-good (e.g., Aoki, 2001; Carvalho, 2006; Barsky et al., 2007) and multi-country framework (e.g., Obstfeld and Rogoff, 1996; Benigno and Benigno, 2003; Benigno, 2004; Corsetti and Pesenti, 2005; Corsetti et al., 2011; Bergin and Corsetti, 2016). These studies emphasize the role of the short-run stability of relative prices. In the short-run open-economy models, the nominal exchange rate plays the central role on pattern of trade and welfare. As Corsetti et al. (2011) summarize, in the short-run, a change in the monetary policy generates a change in the nominal exchange rate, so that the devaluation of exchange rate has an important policy implications. Besides, a temporary change in the monetary policy leads to a change in the terms of trade, which also affects resource allocations in the short-run. For example, Bergin and Corsetti (2016) study the effect of the short-run change in the terms of trade on the real-side through changes in the firm's entry decisions. Contrary to these existing studies, the present paper highlights the long-run consequences in the sense that the nominal exchange rate is perfectly adjusted. Nevertheless, the nominal-side parameters are important determinants of equilibrium allocations, and the optimal inflation rate is non-zero. This discovery is fundamentally different from many existing open-economy monetary studies.

Second, this paper provides a new determinant of the comparative advantage, and examines a policy relevant for the determinant. Ricardian models in which labor productivity is exogenously given are empirically successful for explaining cross-country trade (Eaton and Kortum, 2002; Costinot et al., 2012) and income levels (Alvarez and Lucas, 2007; Waugh, 2010). Yet, these papers do not explore the source of cross-country, cross-industry productivity differences. This paper complements these papers by examining the determinants of the industry-level productivity.[5] A unique finding is that the nominal-side is a determinant of the industry-level productivity, and hence the nominal-side affects the long-run (steady state) pattern of trade. In this sense, the model shows a break of the classical dichotomy. The mechanism behind the optimal inflation rate draws from a classical international trade literature. The reverse version of the immiserizing growth (Johnson, 1955; Bhagwati, 1958). The immiserizing growth usually refers that technological improvement of exporting sector hurts the home country through a deterioration of the terms of trade.[6] Here, positive inflation leads to the welfare gain by dropping the industry-level productivity of exporting industry, and hence by improving the terms of trade.

[5]Matsuyama (2005) explains productivity difference as a result of severity of contractual problem. Ishise (2016) appeals the fact that capital goods are heterogeneous in their productivity, and shows that the shape of the individual productivity distribution is a determinant of the industry-level productivity in a Ricardian framework.

[6]Literature usually consider the immiseirising growth in the context of Heckscher-Ohlin model. A notable exception is Matsuyama (2000). Sawada (2009) empirically shows the plausibility of the immiserizing growth.

2 Model

This section presents the model, and shows the industry-level implications of the model. The setup basically extends the standard cash-less Calvo sticky price with trend inflation (e.g., Ascari and Sbordone, 2014) to a multiple goods and trade. The separate appendix shows detailed derivations.

2.1 Environment

There are two countries, the home and foreign. The foreign country is considered to be the aggregate rest of the world. The government of the home country controls the country's inflation rate, but not the foreign country. The asterisk (*) represents foreign variables if necessary. Time is discrete and infinite horizon denoted by $t = 0, ..., \infty$. The model involves an explicit stochastic dynamic problem, while the analysis focuses on the long-run stationary state in which the aggregate and industry-level variables stay constant. For simplicity, the international financial transaction is dropped, and the period-by-period trade balance is imposed.

There are two final goods indexed by $i = A, B$. Final goods are internationally tradeable without any trade costs. Final goods producers face the perfect competition in their output market. Final good producers in both countries can produce identical final goods, while producers in each country use country- and industry-specific intermediate inputs. Intermediate inputs are nontradeable, and distinguished by variety. Intermediate production uses labor as the only input. Intermediate producers face monopolistic competition in their output market. Their price setting is subject to the probabilistic opportunity of a price adjustment ("Calvo" friction).

Parameters are symmetric across countries, except for (1) population size (N and N^*), (2) gross inflation rate (Π and Π^*), (3) exogenous labor productivity (θ_i and θ_i^*), and (4) the probability of price adjustment (ω_i and ω_i^*).

2.2 Households

There is a representative household in each country, and the representative household consumes final goods (c_{it}), supplies homogeneous labor (l_t) to earn the real wage (w_t), transacts bonds (b_t), pays or receives lump-sum tax/transfer from the government (τ_{Lt}), and receives real profits of the firms (f_t). The household maximizes the expected life-time utility

$$\max_{\{\{c_{it}\}_i, l_t, b_{t+1}\}} E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, l_t), \tag{1}$$

where

$$u(c, l) = c^{\psi} (1 - l)^{1-\psi}, \tag{2}$$

$$c_t = \left(\sum_i \alpha_i c_{it}^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}}, \quad \left(\text{where } \alpha_i \in [0, 1], \ \sum_i \alpha_i = 1, \ \rho > 0 \right), \tag{3}$$

subject to the period budget constraint,

$$\sum_i \frac{P_{it}}{P_t} c_{it} + b_t + \tau_{Lt} = \frac{1 + i_{t-1}}{\Pi_t} b_{t-1} + w_t l_t + f_t, \tag{4}$$

and the appropriate transversality condition. P_t is the nominal aggregate price index, P_{it} is the nominal price of the good $i = \{A, B\}$, i_t is the nominal interest rate associated with the bond holdings, $\Pi_t \equiv P_t/P_{t-1}$ is the inflation rate of the aggregate price index of the country, β is discount factor, ψ is consumption share in the period utility, α_i is the share parameter of different final goods, and ρ is the elasticity of substitution. Let Λ_{tt+j} denote the ratio of marginal utilities of consumption ("stochastic discount factor" in the macro-finance term),

$$\Lambda_{tt+j} \equiv \beta^j \frac{u_{ct+j}}{u_{ct}}. \tag{5}$$

2.3 Production

2.3.1 Final goods producers

Final goods producers produce internationally tradeable final goods using differentiated intermediate inputs. Production technology is described as a constant-elasticity-of-substitution production function, and they face perfect competition in their output market. The maximization problem is

$$\max \frac{P_{it}}{P_t} y_{it} - \int_0^1 \frac{P_{it}(\upsilon)}{P_t} y_{it}(\upsilon) \mathrm{d}\upsilon, \tag{6}$$

subject to

$$y_{it} = \left(\int_0^1 y_{it}(\upsilon)^{\frac{\eta-1}{\eta}} \mathrm{d}\upsilon \right)^{\frac{\eta}{\eta-1}}, \tag{7}$$

where υ is the index of the differentiated input, and η is the elasticity of substitution.[7] From the profit optimization problem, the demand for each input variety is

$$y_{it}(\upsilon) = \left(\frac{P_{it}}{P_{it}(\upsilon)} \right)^{\eta} y_{it}, \tag{8}$$

and the price of the industrial product is

$$P_{it} = \left(\int_0^1 P_{it}(\upsilon)^{1-\eta} \mathrm{d}\upsilon \right)^{\frac{1}{1-\eta}}. \tag{9}$$

[7] The parameter η is assumed to be uniform across countries and industries for the simplicity of the presentation. The appendix shows derivations allowing cross-country, cross-industry differences in this parameter.

2.3.2 Intermediate input producer

Each intermediate input producer produces a differentiated product. Each input producer has an access to a production technology using labor as the only input, and faces the industry-wide labor productivity θ_{it}.[8] Production exhibits the CRS or DRS, depending on the scale parameter $\gamma \in (0, 1]$. The wage payment is subsidized (if $\tau_{it} > 0$) or not (if $\tau_{it} = 0$). This subsidy is widely used in the literature to eliminate distortion caused by monopolistic competition (Benigno and Woodford, 2005; Schmitt-Grohé and Uribe, 2007).

An input producer sets own price to maximize its profits, while not all the period can it adjust the price. In each period, a producer can adjust price with probability of $1 - \omega_i$.[9] Given this "Calvo" adjustment friction, a firm maximizes present discounted value of the profits stream during the non-adjustment period. The profits in period $t + j$ are evaluated by the stochastic discount factor of the country's representative household, Λ_{tt+j}, so that each intermediate producer's problem is

$$\max E_t \sum_{j=0}^{\infty} \Lambda_{tt+j} \omega_i{}^j \left[\frac{P_{it}(\upsilon)}{P_{t+j}} y_{it+j}(\upsilon) - (1 - \tau_{it+j}) w_{t+j} l_{it+j}(\upsilon) \right], \tag{10}$$

subject to the production technology,

$$y_{it+j}(\upsilon) = \theta_{it+j} l_{it+j}(\upsilon)^{\gamma}, \tag{11}$$

and the demand (8) in which the own price ($P_{it}(\upsilon)$) will be fixed over $j = 1, 2, ...$,

$$y_{it+j}(\upsilon) = \left(\frac{P_{it+j}}{P_{it}(\upsilon)} \right)^{\eta} y_{it+j}. \tag{12}$$

When a firm has chance to adjust its price, the optimal price choice is symmetric across those who adjust in the industry. The optimal price ($\tilde{P}_{it}$) satisfies

$$\left(\frac{\tilde{P}_{it}}{P_{it}} \right)^{1-\eta+\frac{\eta}{\gamma}} = \frac{\eta}{\eta - 1} \frac{E_t \sum_{j=0}^{\infty} \Lambda_{tt+j} \omega_i^j \left(\frac{P_{it+j}}{P_{it}} \right)^{\frac{\eta}{\gamma}} (1 - \tau_{it+j}) \frac{w_{t+j}}{\gamma} \left(\frac{y_{it+j}}{\theta_{it+j}} \right)^{\frac{1}{\gamma}}}{E_t \sum_{j=0}^{\infty} \Lambda_{tt+j} \omega_i^j \frac{P_{it+j}}{P_{t+j}} \left(\frac{P_{it+j}}{P_{it}} \right)^{\eta-1} y_{it+j}}. \tag{13}$$

[8] Including capital stock as an input is a straightforward extension. However, as shown by Baxter (1992), due to the endogenous accumulation of capital, returns on investment are equalized across industries in the long-run steady state. In this sense, the model with capital is essentially the same as model without capital.

[9] For simplicity, this presentation drops the possibility of price indexation (automatic updating of the price in a certain rate). The derivations in the Appendix includes the indexation. Results are qualitatively robust unless the indexation is perfect.

2.3.3 Law of the industry price motion and the industry aggregate

From (9), the industry-level price is the weighted average of the adjusted and non-adjusted prices,

$$P_{it} = \left(\omega_i P_{it-1}^{1-\eta} + (1-\omega_i)\tilde{P}_{it}^{1-\eta}\right)^{\frac{1}{1-\eta}}. \tag{14}$$

Industry-level output is obtained first by combining (8) and (11),

$$y_{it}\left(\frac{P_{it}}{\tilde{P}_{it}}\right)^{\eta} = \theta_{it} l_{it}(\upsilon)^{\gamma}, \tag{15}$$

and then integrating over variety,

$$y_{it} = \frac{\theta_{it}}{{s_{it}}^{\gamma}} l_{it}^{\gamma} \tag{16}$$

where $s_{it} = \int_0^1 \left(\frac{P_{it}}{\tilde{P}_{it}}\right)^{\frac{\eta}{\gamma}} \mathrm{d}\upsilon$ and $l_{it} = \int_0^1 l_{it}(\upsilon)\mathrm{d}\upsilon$. The variable s_{it} captures the dispersion cost as explained in the following subsection.

2.4 Equilibrium and steady state

The government budget is balanced

$$\sum_i \int_0^1 \tau_{it} w_t l_{it}(\upsilon)\mathrm{d}\upsilon + \tau_{Lt} = 0. \tag{17}$$

Bond and labor markets clearing conditions are

$$b_t = 0, \tag{18}$$

$$\sum_i l_{it} = l_t \tag{19}$$

Trade balance is

$$\sum_i P_{it}(y_{it} - c_{it}) = 0. \tag{20}$$

Under the assumption of costless final goods trade, the final goods market clearing condition for each i is

$$N c_{it} + N^* c_{it}^* = N y_{it} + N^* y_{it}^*, \tag{21}$$

where N and N^* are population size, and c_{it}^* and y_{it}^* are foreign consumption and production of the good i, respectively. As a simple abstraction, the home government directly chooses the aggregate inflation rate of the country Π_t. The choice of the inflation rate is called as the monetary policy. The equilibrium is then defined as the standard manner.

In this model, the law of one price holds for each final goods market, and hence the purchasing power parity holds. The nominal exchange rate is the ratio of the foreign and home price indices.

2.4.1 Steady state and key industry-level implications

The following analysis focuses on the steady state (more precisely, stationary state) in which (1) productivity is constant, (2) the industry-level and aggregate allocations are constant, and (3) the aggregate price grows at rate Π (and Π^* in the foreign).[10] The main analysis is comparative statics of the welfare with respect to a change in Π, the home country's trend inflation rate.[11]

The industry prices grow at rate Π (and Π^*), and the nominal exchange rate is fully adjusted.[12] From (16), the industry-level output is expressed as

$$y_i = \frac{\theta_i}{s_i^\gamma} l_i^\gamma \tag{22}$$

where the dispersion cost term, s_i, is

$$s_i = \frac{1-\omega_i}{1-\omega_i \Pi^{\frac{\eta}{\gamma}}} \left(\frac{1-\omega_i \Pi^{\eta-1}}{1-\omega_i} \right)^{\frac{\eta}{\eta-1}\frac{1}{\gamma}}. \tag{23}$$

From (13) and (14), the industry-level relative price is expressed as

$$p_i = (1-\tau_i)\, v_i \frac{s_i^\gamma}{\theta_i} \frac{w}{\gamma} l_i^{1-\gamma}, \tag{24}$$

where the markup term, v_i, is

$$v_i = \frac{\eta}{\eta-1} \frac{1-\beta\omega_i \Pi^{\eta-1}}{1-\beta\omega_i \Pi^{\frac{\eta}{\gamma}}} \frac{1-\omega_i \Pi^{\frac{\eta}{\gamma}}}{1-\omega_i \Pi^{\eta-1}}. \tag{25}$$

Note that when deriving p_i in the steady state, one needs to calculate the infinite sums in (13). Parameter space is restricted to ensure the finiteness of the infinite sums (c.f., p.693, Ascari and Sbordone, 2014).[13] In particular, throughout the paper, the following assumption is imposed.

Assumption 1. $\beta \in (0,1)$, $\eta > 1$, $\omega_i \in [0,1)$, and $\beta\omega_i \Pi^{\frac{\eta}{\gamma}} < 1$.

[10] Output, labor, and price of each variety differ over time.

[11] Since the government maximization problem is not explicitly considered, Π is treated as a parameter.

[12] Since the real exchange rate is always unity, the nominal exchange rate is the price ratio: $e_t = P_t/P_t^*$. Then in the steady state, the nominal exchange rate grows at a constant rate: $e_t = e_0 (\Pi/\Pi^*)^t$.

[13] Although Ascari and Sbordone (2014) do not give economic intuitions behind the assumption, the idea is as follows. Basically, the assumption is satisfied if (1) household is impatient, (2) probability of price change is high, (3) inflation rate is low (and the assumption is always satisfied under deflation), (4) substitutability among variety is low, and (5) returns to scale is high. The assumption basically ensures the firms to be operate. Otherwise, expected present discounted value of firm's profits become negative, so that the firms do not operate. Under inflation, the price of a firm who cannot adjust price for many period becomes relatively too low so that period profits become negative. High inflation leads to rapid deterioration of the price, and hence the possibility of negative profits is high. A firm earns large negative profits through large sales if the variety is easily substitutable to other varieties. The expected future negative profits are large if the probability of price change is low. Given exponential aggregate price growth (through constant inflation rate), the price of the non-adjusting firm becomes low at the exponential rate, so that the future negative profits grows at exponential rate. However, the expected positive profits after price adjustment is constant. Hence, if household is patient, the effect of expected future negative profits dominates the profits after the price adjustment.

In the analysis of trade equilibria, (22)–(25) play the central role. In the single-good, CRS models, Schmitt-Grohé and Uribe (2006) show the properties of s_i in a dynamic setting, King and Wolman (1999) quantitatively examine the properties of v_i.[14], and Ascari and Sbordone (2014) quantitatively examine the steady state properties. Damjanovic and Nolan (2010) analyze the properties of s_i in a single-good DRS setting. The following Lemma 1 summarizes properties of s_i and v_i in the steady state.

Lemma 1. *Under Assumption 1,*

1. *If* $\omega_i = 0$ *or* $\Pi = 1$*, then* $s_i^\gamma = 1$*,* $v_i = \eta/(\eta - 1)$*.*
2. *If* $\beta \to 1$*, then* $v_i \to \eta/(\eta - 1)$*.*
3. $\partial s_i^\gamma / \partial \Pi \gtreqless 0$ *if* $\Pi \gtreqless 1$*.*
4. *For small* $\varepsilon > 0$*,* $s_i^\gamma|_{\Pi=1+\varepsilon} > s_i^\gamma|_{\Pi=1-\varepsilon}$ *under usual parameter values.*
5. $\partial v_i / \partial \Pi|_{\Pi=1} < 0$*.*

Proof. See Appendix for the derivations and the precise conditions. □

Figure 1 shows s_i, v_i (relative to $\eta/(\eta - 1)$, i.e., v_i when $\Pi = 1$), and the normalized relative price ($s_i v_i$, relative to $s_i v_i$ when $\Pi = 1$), against Π under a set of typical parameter values.[15] One period of the model is a month, but the gross inflation rate, Π, in the figures is in the annualized value.

The variable v_i captures the markup. The markup consists of the exogenous component coming from the monopolistic competition ($\eta/(\eta-1)$), and the remaining term that depends on the nominal-side. This additional term appears because, as discussed by King and Wolman (1999), under trend inflation, the firms who are do not revise the price face a gradual deterioration of the markup. The firms who revise the price know this deterioration so that they set higher markup than the "fundamental" markup. The steady state industry-level average markup is the average of these two effects. On average, the effect of the non-adjusting firms dominates the effect of the adjusting firms.

The variable s_i captures the cost of price dispersion. Under the price rigidity, the firm's price setting is not optimal in the period-by-period sense, neither is the production. In particular, under trend inflation, the price of the non-adjusting firms are lower than the price of the adjusting firms. The price variation creates asymmetry in production across ex ante symmetric varieties. As a result, some firms produce too much and others produce too less. That is, some firms employ too much labor and others employ too less. In the aggregate level, this allocation inefficiency appears as a resource cost. Notice that even with price rigidity, under zero-inflation, non-adjusting firms do not face automatic price deterioration and hence do not need to employ too much labor. The economy incurs no dispersion cost under zero-inflation steady state.

Several implications are in order. First, under zero-inflation (or no price rigidity, $\omega_i = 0$), the nominal-side plays no role. In this case, $s_i = 1$, and $v_i = \eta/(\eta - 1)$ becomes the "fundamental" markup. The

[14] King and Wolman (1999) set up price rigidity differently.

[15] The values are $\gamma = 1$, $\eta = 10$, $\omega = 11/12$, and $\beta = (1/1.04)^{1/12}$. Under these values, the fundamental markup ($\eta/(\eta-1)$) is 11%, the average life of the price is 12 months, and the annual real interest rate is 4%. These values are monthly equivalent values in Ascari and Sbordone (2014).

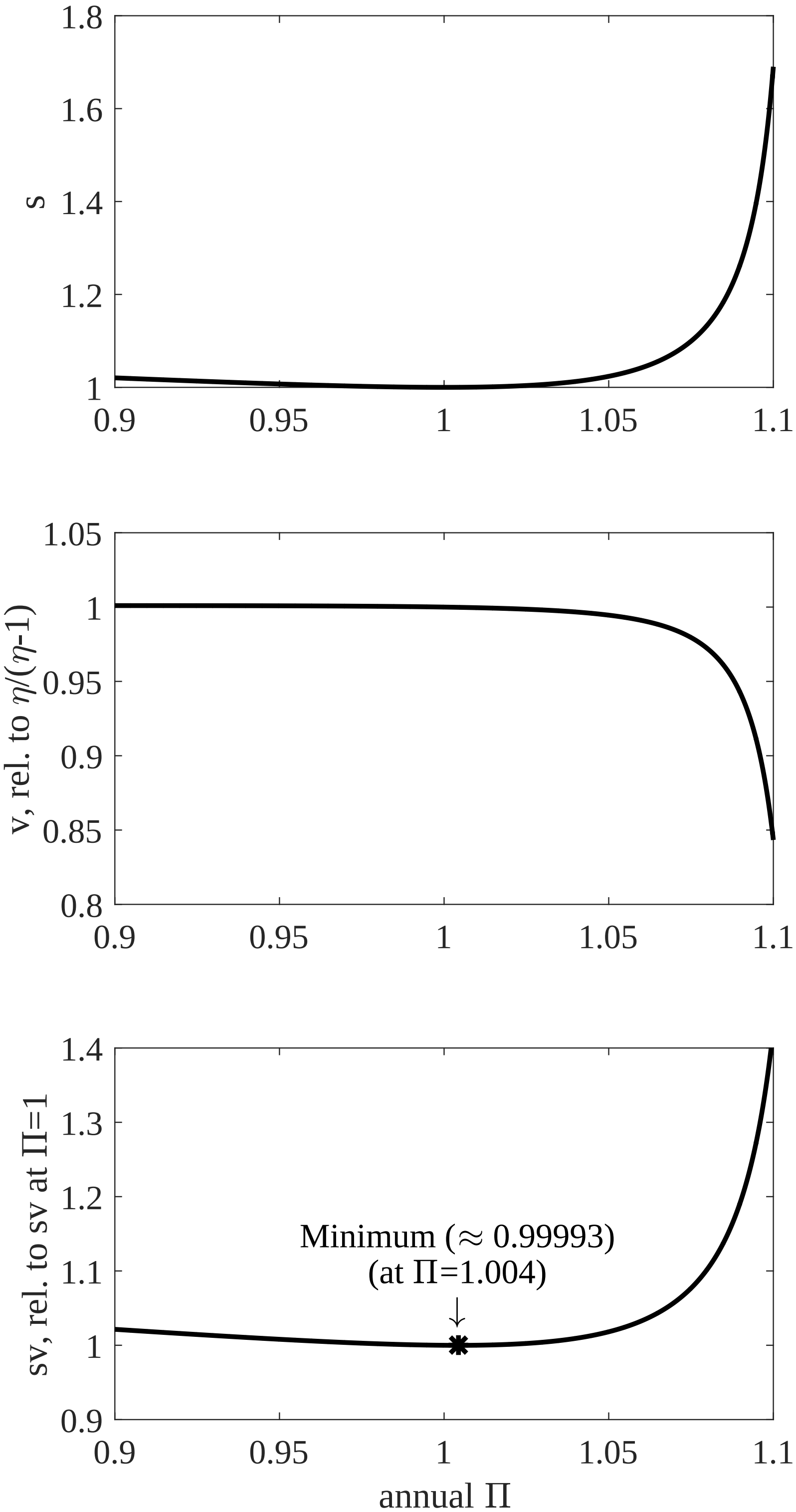

Figure 1: The dispersion cost, the markup and the normalized relative price

dispersion cost achieves this minimum at $\Pi = 1$. As Π diverges from one, the dispersion cost increases. In the steady state, the dispersion cost is asymmetric in a sense that 1% inflation is more costly (in terms of productivity) than 1% deflation. This asymmetry comes from the fact that under deflation, firms who revise the price set lower price, and the price gradually becomes over-pricing. The economy-wide cost of this initial under-pricing actually eliminates the cost of over-pricing due to the monopolistic competition.

The middle panel of Figure 1 shows that the markup term is decreasing in Π. Precisely, v_i is decreasing when $\Pi \geq 1$, but not determined when $\Pi < 1$. However, under usual parameter values, s_i is decreasing in Π.

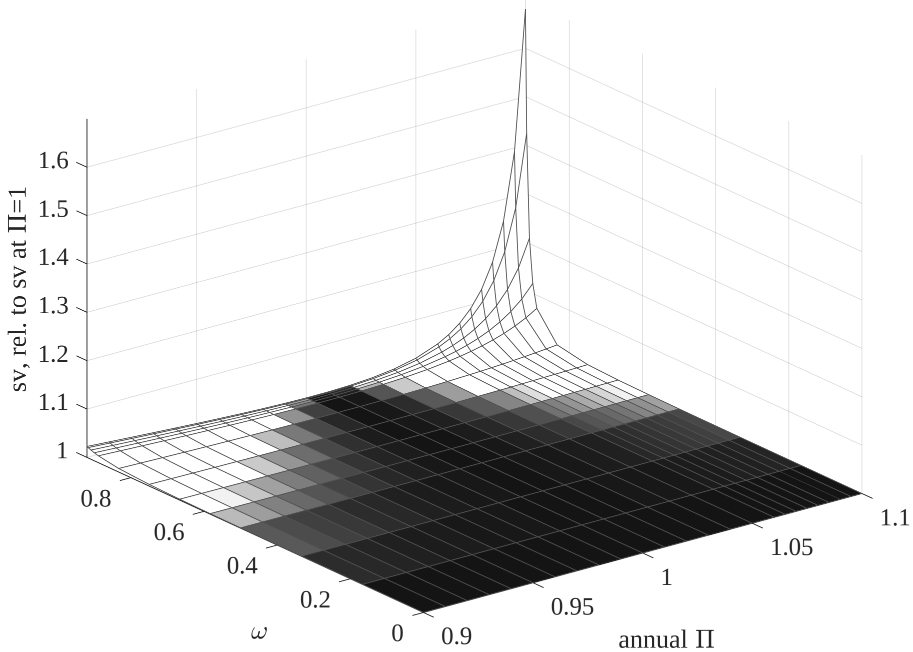

Figure 2: The (normalized) relative price

Given the shapes of s_i and v_i, the relative price of the industry also depends on Π. The relative price p_i is proportional to the product of s_i and v_i. The price is minimized at the inflation rate slightly higher than zero (indicated by * mark in the figure). Finally, Figure 2 shows the normalized relative price $(s_i v_i)$ against Π and ω_i. If ω_i is small (high frequency of price change), then the inflation rate plays negligible role to determine the price. As ω_i increases, the effect increases.

3 Results

This section shows the results.[16] The baseline result is shown in the context of the assumption of the CRS ($\gamma = 1$). In this case, open-economy is described by Ricardian trade model. As a reference, the analysis starts from the single-good autarky case, and the open-economy case follows. Then, a case of DRS and its quantitative implications are presented.

[16] Appendix shows derivations.

3.1 Autarky

3.1.1 Single-good

Under the single-good autarky, the standard result holds: the welfare is maximized when Π is slightly higher than 1 (King and Wolman, 1999). In particular, the steady state welfare, $u(c, l)$, is

$$u = c^{\psi}(1-l)^{1-\psi} = (s(1-\tau)v)^{-\psi}\left(\frac{\psi}{(1-\tau)v} + 1 - \psi\right)^{-1} \tag{26}$$

If v is constant, then the welfare is maximized where s is minimized. Otherwise, the welfare depends on two effects. Since v is decreasing in Π, the second term is decreasing in v. Given the fact that sv is minimized at the rate slightly higher than unity, the welfare is maximized somewhere between this positive rate and zero.

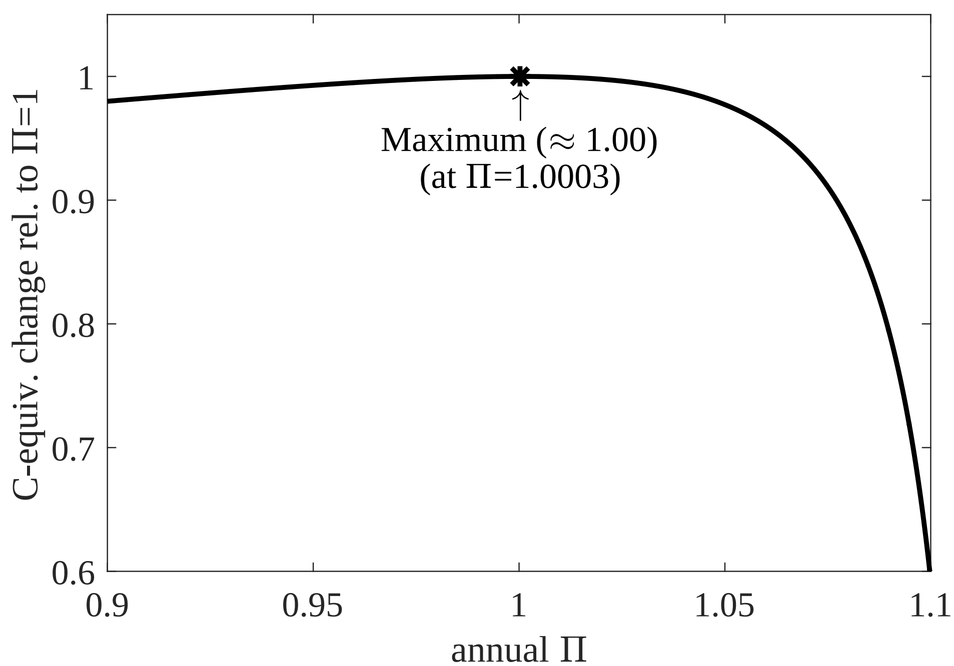

Figure 3: Consumption-equivalent changes in the welfare under single-good autarky

Figure 3 shows a numerical example.[17] The welfare is maximized at the inflation rate slightly higher than zero, but the consumption gain compared with the zero-inflation is negligible.[18] The effect becomes not small when the inflation rate largely differs from zero. Under high inflation rate (e.g., 10% per year), the consumption loss is approximately 40%.

Given this minimal role of v_i, most of the following analyses focus on the usual case in which the markup distortion is eliminated.

Assumption 2. $(1-\tau_i)v_i = 1$.

[17]Parameters are: $\eta = 10$, $\omega = 11/12$, $\beta = (1/1.04)^{1/12}$, and $\psi = 1/3$.

[18]Throughout the section, figures of the welfare changes are based on the household's utility in the steady state, and expressed as consumption equivalent terms (in which the welfare at $\Pi = 1$ is the baseline).

This assumption leads to simplicity of analytical results.

3.1.2 Multi-good

When there are two goods, the welfare is expressed as a generalized version of (26), which depends on s_A, s_B, and other factors. Intuitively, the welfare is the weighted average of price and markup distortions of two goods. If two goods are symmetric, the expression reduces to (26).

Under autarky, using (24) when $\gamma = 1$, the relative price of final goods is,

$$\frac{p_A}{p_B} = \frac{1-\tau_A}{1-\tau_B}\frac{v_A}{v_B}\frac{s_A}{s_B}\frac{\theta_B}{\theta_A}. \tag{27}$$

As in the standard Ricardian model, the production-side parameters determine the relative price, and the household-side parameters play no role. However, contrary to the standard Ricardian model, the relative price depends not only on the aggregate productivity but also on the markup due to the underlying monopolistic competition structure. This relative price under autarky is the critical variable to determine the trade pattern when the economy engages in costless trade.

3.2 Two-country: Ricardian model

3.2.1 Nominal-side as a source of comparative advantage

International trade is allowed only for the final goods, and the final goods markets are perfectly competitive. The industry-level technology is expressed as a linear-in-labor function. As a result, the model essentially implies the Ricardian trade structure. The comparative advantage is determined by the autarky relative prices of two countries. Costless trade equilibrium is then determined as the textbook Ricardian model (See, for example, Ch. 1 of Feenstra, 2016)

A new implication is that the nominal-side parameters are determinants of comparative advantage. Holding other things being constant, an industry whose price rigidity is small (high frequency of price change), the industry-level productivity is high. It then implies that a country is more likely to have comparative advantage in this sector. Even if there are no fundamental technological difference across countries, $\theta_i = \theta_i^*$ for $i = A, B$, a difference in ω_i and ω_i^* creates comparative advantage. Furthermore, even without differences in ω_i and ω_i^* across countries, if ω_i differ across industries, and the inflation rate is non-zero, the relative price is affected. For example, if Π is extremely high in a country, the output price of an industry with lower frequency of price adjustment is higher than the price of an industry with higher frequency of price adjustment. Regardless of source, cross-industry, cross-country (real) price difference is a determinant of comparative advantage.

Suppose that the home country posses comparative advantage in producing good A, while the foreign country posses comparative advantage in B. This is true if the relative price of the home under autarky is lower than that of the foreign,

$$\frac{1-\tau_A}{1-\tau_B}\frac{v_A}{v_B}\frac{s_A}{s_B}\frac{\theta_B}{\theta_A} < \frac{1-\tau_A^*}{1-\tau_B^*}\frac{v_A^*}{v_B^*}\frac{s_A^*}{s_B^*}\frac{\theta_B^*}{\theta_A^*}. \tag{28}$$

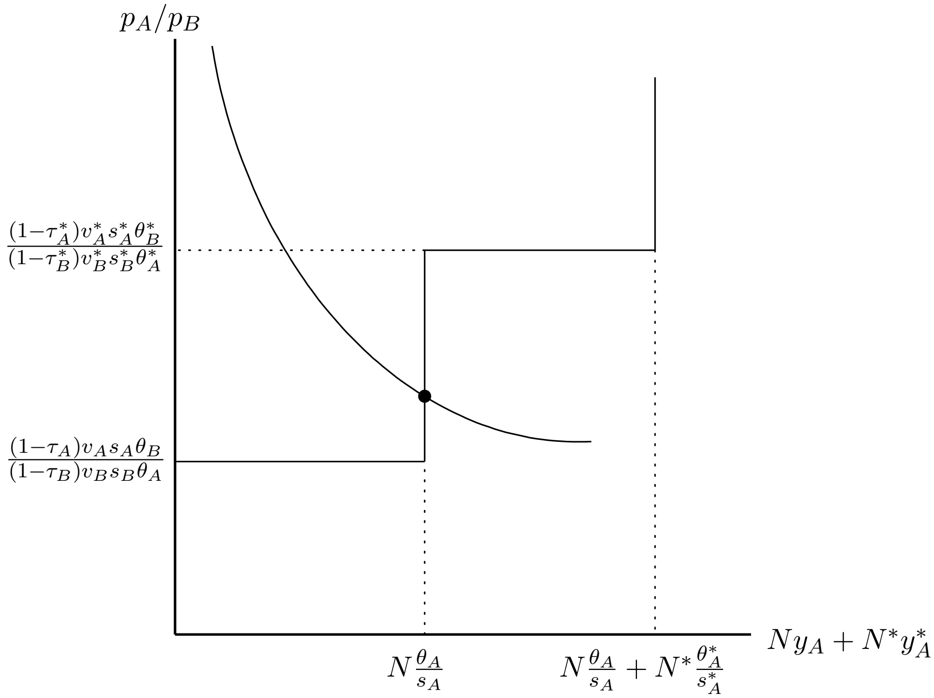

Figure 4: Costless trade equilibrium of two-good model

As in the standard Ricardian model, the world supply curve of a final good is a stair-step shape, which is shown in Figure 4. Given the downward world demand curve, there are three possible equilibria. First, if the demand curve crosses the lower-step, the world equilibrium relative price is the same as the home's autarky relative price. The home produces A and B, and the foreign produces B. Second, if the demand curve crosses the middle vertical line, the world equilibrium relative price is in-between the autarky prices of both countries. The home produces A, and the foreign produces B. Third, if the demand curve crosses the upper-step, the world equilibrium relative price is the same as the foregin's autarky relative price. The home produces A, and the foreign produces A and B. In summary,

Proposition 1. *Consider a two-country, two-good model. Under costless trade, specialization pattern is determined by the autarky relative prices of two countries, which depend on the exogenous productivity, the dispersion cost, and the markup terms. The dispersion cost and markup terms in turn depend on price rigidity and the inflation rate. As Ricardian model, the world supply curve in the steady state has a stair-step pattern.*

3.2.2 Terms of trade

Suppose that each country completely specializes in which the home produces good A and the foreign produces good B.[19] The open-economy equilibrium relative price is

$$\frac{p_A}{p_B} = \frac{\alpha_A}{\alpha_B} \left(\frac{\theta_B^*}{\theta_A} \frac{s_A}{s_B^*} \frac{N^*}{N} \frac{\psi + (1-\tau_A)v_B^*(1-\psi)}{\psi + (1-\tau_B^*)v_B^*(1-\psi)} \right)^{\frac{1}{\rho}}. \tag{29}$$

[19]The following immiserizing growth result holds if the home completely specializes.

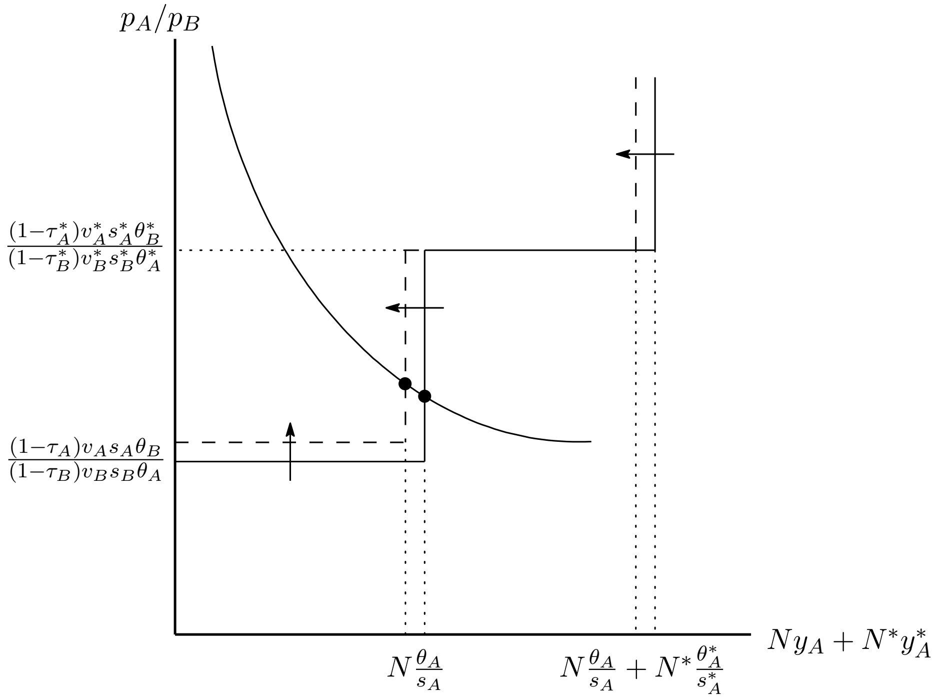

Figure 5: Equilibrium relative price under high and low inflation rate

The relative price is the home country's terms of trade because the home country exports good A and imports good B.

Given (29), an increase in s_A through a deviation from $\Pi = 1$ improves the home country's terms of trade. This improvement simply comes from the fact that an increase in the dispersion cost (s_A) leads to a decrease in the industry-level productivity, and low industry-level productivity is associated with high price in perfectly competitive final goods market. Figure 5 describes the result of high s_A (broken-line) and low s_A. The middle vertical line under high s_A locates to the left of the vertical line under low s_A . Given downward sloping world demand curve, this difference in the vertical line implies the higher relative price (the terms of trade).[20] In summary,

Proposition 2. *Consider a two-country, two-good model where the home specializes good A and the foreign specializes good B production, and assume Assumption 2. The home country's terms of trade improves as* Π *diverges from* 1.

[20]If $|\partial s_A/\partial \Pi| < |\partial s_B/\partial \Pi|$, the lower-step goes down, rather than up. This difference does not affect the effect on the terms of trade.

3.2.3 Welfare enhancing inflation

The welfare of the home country is

$$\begin{aligned}u =&(c)^{\psi}(1-l)^{1-\psi}\\ =&\left(\frac{\psi}{1-\psi}\right)^{\psi}\left(\frac{\theta_A}{(1-\tau_A)v_A s_A}\left(\alpha_A^{\rho}+\alpha_B\alpha_A^{\rho-1}\left(\frac{\theta_B^*}{\theta_A}\frac{s_A}{s_B^*}\frac{N^*}{N}\frac{\psi+(1-\tau_A)v_A(1-\psi)}{\psi+(1-\tau_B^*)v_B^*(1-\psi)}\right)^{\frac{\rho-1}{\rho}}\right)^{\frac{1}{\rho-1}}\right)^{\psi}\\ &\times\frac{(1-\tau_A)v_A(1-\psi)}{\psi+(1-\tau_A)v_A(1-\psi)}.\end{aligned}\tag{30}$$

Suppose now that the markup distortion is dropped (by Assumption 2). Remember that under autarky the optimal inflation rate is unity. The welfare in an open-economy equilibrium also depends on Π, and

$$\frac{\partial u}{\partial \Pi}\frac{\Pi}{u}=-\frac{\psi\alpha_A^{\rho}}{\alpha_A^{\rho}+\alpha_B\alpha_A^{\rho-1}\left(\frac{\theta_B^*}{\theta_A}\frac{s_A}{s_B^*}\frac{N^*}{N}\right)^{\frac{\rho-1}{\rho}}}\left(1-\frac{1-\rho}{\rho}\frac{\alpha_B}{\alpha_A}\left(\frac{\theta_B^*}{\theta_A}\frac{s_A}{s_B^*}\frac{N^*}{N}\right)^{\frac{\rho-1}{\rho}}\right)\frac{\partial s_A}{\partial \Pi}\frac{\Pi}{s_A}\tag{31}$$

The first term is always positive. The second term (inside of the parentheses) can be positive or negative depending on the parameter values. The last term follows Lemma 1. Hence, if the second term is positive, zero-inflation maximizes the welfare as autarky case. However, if the second term is negative, the welfare increases as Π diverges from 1. In summary,

Proposition 3. *Consider a two-country, two-good model where the home specializes good A and the foreign specializes good B production. Suppose that the markup distortion is dropped by Assumption 2. The home country's welfare increases as* Π *diverges from* 1 *if*

$$\frac{1-\rho}{\rho}\frac{\alpha_B}{\alpha_A}\left(\frac{\theta_B^*}{\theta_A}\frac{s_A}{s_B^*}\frac{N^*}{N}\right)^{\frac{\rho-1}{\rho}}>1.\tag{32}$$

The condition has two parts. First, $\rho<1$. This means that the magnitude of complementarity of two final goods is stronger than the Cobb-Douglas ($\rho=1$) situation. Second, given $\rho<1$, the condition holds if (1) ρ is small, (2) α_B is large, (3) θ_A/θ_B^* is large, (4) s_B^*/s_A is large, and (5) N/N^* is large. In words, if a large country exports essential goods using highly productive technology but the goods are not large in the budget share, then the welfare gain is more likely.

The change in the welfare depends on two effects. A change in the terms of trade is positive for the welfare. At the same time, a reduction of productivity reduces the output of the country. The output reduction itself leads to a home's welfare loss. Hence, the home's welfare depends on which effect dominates. Under the above condition, the gains from the terms of trade defeats the loss from the output reduction.

Figure 6 describes the result by showing home country's production possibility frontiers (straight lines), budget constraints (broken lines), and indifference curves under different inflation rate. Suppose that one situation is $\Pi=1$ (which is shown without apostrophe), and the other for $\Pi>1$ or $\Pi<1$

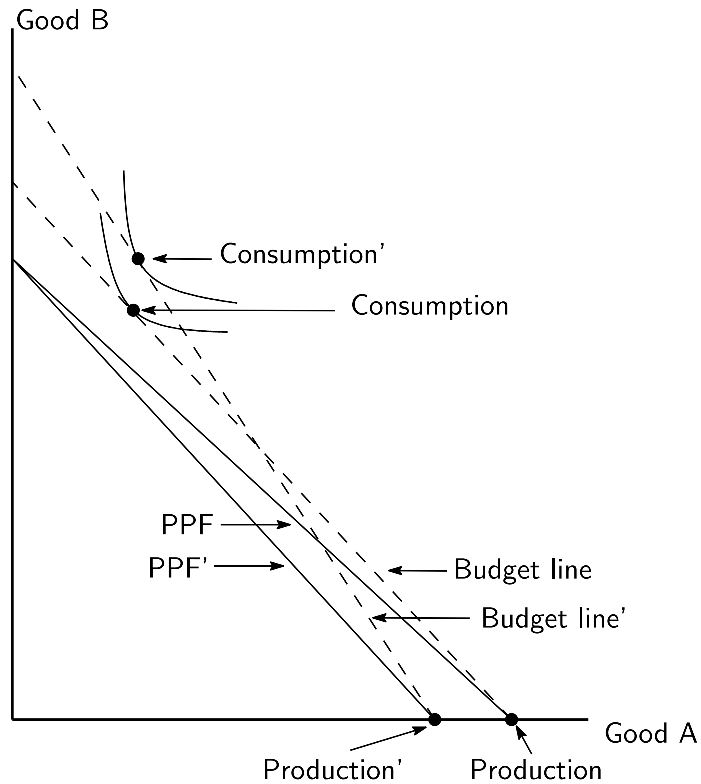

Figure 6: The effect of non-zero inflation

(with apostrophe). As seen in Lemma 1, deviating from $\Pi = 1$ leads to a reduction in the industry-level productivity through increasing the dispersion cost. The production possibility frontier (PPF) captures the difference in the industry-level productivity: PPF' locates inside of the PPF. Under the situation that the specialization pattern is the same, the country produces good A only. At the same time, the lower industry-level productivity is associated with the higher terms of trade. The budget line (which captures the relative price of A in terms of B, i.e., the terms of trade) is steeper for the non-zero inflation rate case than for the zero-inflation case. The steeper slope of the budget line may not necessarily lead to the higher utility. Under a certain condition (notably, in the figure, $\alpha_B >> \alpha_A$), the higher utility is attained under the non-zero inflation rate.

In Figure 6 the home's productivity of good B is unchanged. This is not a required assumption. Instead, the productivity of the other industry (which is not producing) can also be decreasing in Π. As long as specialization patten is unchanged, the welfare result holds. Since a parallel shift in the home's PPF ensures no change in the specialization pattern, a reduction in the industry-level productivity of non-producing industry helps to sustain the main result.

The reverse version, i.e., the welfare loss through technology improvement, is classically known as the immiserizing growth (Johnson, 1955; Bhagwati, 1958). The literature usually describes the immiserizing growth as a result of exogenous technological growth. Here, the manipulation of the terms of trade is the result of the policy change.

The dashed-line of Figure 7 shows a numerical example of the effect when $\rho = 0.5$.[21] Contrary to the

[21] The other parameter values are: $\eta = 10$, $\omega_i = \omega_i^* = 11/12$, $\beta = 0.9967$, $\psi = 1/3$, $\theta_B^*/\theta_A^* = 1$, $s_B^* = 1$, $\alpha_A = 0.1$,

single-good autarky case, the welfare is *minimized* at $\Pi = 1$. The effect is not large for 1–2% inflation or deflation, but is nonnegligible when the inflation rate is large. In terms of deflation/inflation, the welfare gain is larger for 10% inflation than 10% deflation, reflecting the asymmetry of the dispersion cost.

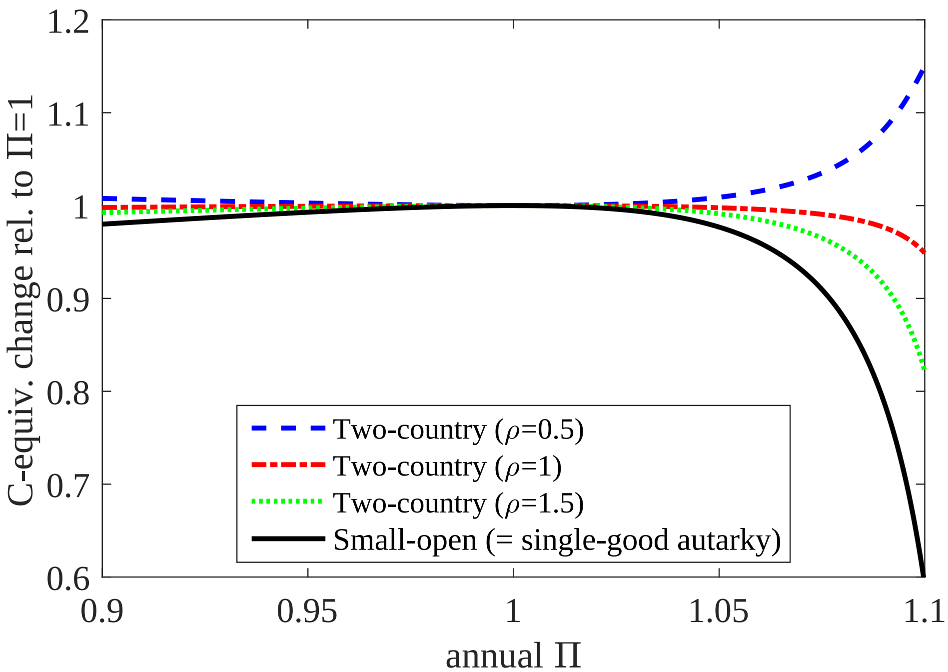

Figure 7: Consumption-equivalent changes in the welfare under single-good autarky, small-open, and two-country models with various parameterizations

The figure shows that higher inflation (or lower and lower deflation) is better, but there is a limitation. If productivity drop is large enough to break (28), the trade pattern changes. The welfare calculation (31) is not applicable. In this sense, the welfare improvement is local, not global, effect.

3.3 Small-open economy

The welfare minimization of zero-inflation is possible under restrictive set of parameters. However, the positive impact of the terms of trade on the welfare is a generic result.

In the two-country model, the source of welfare improvement is a change in the terms of trade. The channel is specific to a two-country model. In fact, the welfare effect of inflation is always negative in closed-economy and small-open economy models. A small-open setting is a case in which the world price (in particular the relative price of goods) is exogenously given, and is constant. Under a small-open setting, changes in the home country do not affect the terms of trade. Hence, the effect of Π on the home's welfare resembles to the closed-economy setting. In particular, under Assumption 2, the welfare loss of the closed and small-open models is just the cost of the price rigidity.

Figure 7 compares the effects of Π on the welfare in a single-good autarky, two-good small-open economy, and two-country model with various ρ values.[22] If good A is the only good in the single-good

$\alpha_B = 0.9$, $N^*/N = 4$.

[22] See footnote 21 for the parameter values.

closed-economy model, the welfare impact of Π is the same for the single-good closed-economy model and the small-open economy model. The loss is purely the resource cost caused by the price rigidity. When the effect of the terms of trade into account, the welfare loss is in general smaller. The loss of the production improves the terms of trade, and this improvement attenuates the loss from the resource cost. The positive impact of the terms of trade exists regardless of the parameter value ρ. Even if two goods are close substitute (ρ is large), a reduction in the capacity of exporting industry leads to an improvement in the terms of trade. Thus, the welfare cost of inflation in a two-county model is smaller than that in a closed-economy or small-open economy model. And as shown in Proposition 3, the positive impact of the terms of trade outperformes the direct negative impact of the resource cost if $\rho < 1$.

3.4 Decreasing-returns-to-scale: Ricardo-Viner trade model

When the intermediate production exhibits DRS ($\gamma < 1$), the aggregate production is also DRS. The international trade model describing the situation is the Ricardo-Viner model (also known as the specific factors model). In this case, both of the two countries produce both of the goods, and exports the goods which a country produces more than the country consumes. As shown in the Appendix, the stationary equilibrium exists and is unique even without Assumption 2.

Proposition 4. *Consider a Ricardo-Viner model (i.e.,* $0 < \gamma < 1$*, and two-country, two-good costless trade model) where the home exports good* A *and the foreign exports good* B*. There exists a unique stationary equilibrium.*

Proof. See Appendix. □

As in CRS case, a change in Π (Π's deviation from one) leads to a change in the terms of trade. Since the home country produces both good A and B, the direction of the change is in general not determined. Under autarky, the relative price depends on $\{\alpha_i, s_i, v_i, \tau_i\}$ and (γ, ρ). In particular, if and only if s_A responds to Π more than s_B (an example of this case is that A is more price sticky sector), then the relative price p_A/p_B increases. When the country exports good A, the relative price depends on the paremeters of the foregin country. The requirement of increasing the relative price (i.e., the terms of trade) is weaker than one under the autarky. Nevertheless, a sufficient condition of the improvement of the terms of trade is A is more sticky than B. That is,

Proposition 5. *Consider a Ricardo-Viner model where the home exports good* A *and the foreign exports good* B*. Suppose Assumption 2 holds. A change in* Π *affects the terms of trade. A sufficient condition that an increase in the terms of trade by* Π*'s deviation from one is*

$$\left|\frac{\partial s_A^\gamma}{\partial \Pi}\frac{\Pi}{s_A^\gamma}\right| \geq \left|\frac{\partial s_B^\gamma}{\partial \Pi}\frac{\Pi}{s_B^\gamma}\right| \tag{33}$$

Proof. See Appendix. □

As in the Ricardian case, the immiserizing growth is possible in this model. Figure 8 illustrates the situation. Compared with Figure 6, the main difference is that the production possibilities frontiers are now bow-shaped curves, rather than the straight-lines.

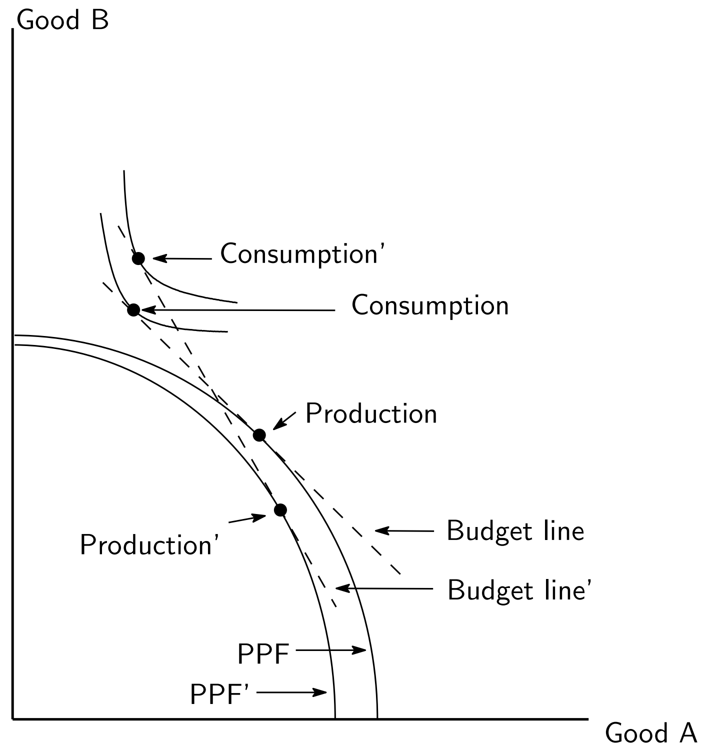

Figure 8: The effect of non-zero inflation in Ricardo-Viner model

Contrary to the CRS case, the conditions for the immiserizing growth involve complicated form, and the condition is not readily interpretable. However, using some endogenous variables, the welfare change is captured by a simple expression.

Proposition 6. *Consider a Ricardo-Viner model where the home exports good A and the foreign exports good B. Suppose Assumption 2 holds. The change in the welfare caused by a change in* Π *is expressed as*

$$\frac{du}{d\Pi}\frac{\Pi}{u} \propto \frac{dw}{d\Pi}\frac{\Pi}{w} = \frac{p_B(y_B - c_B)}{c}\frac{dp}{d\Pi}\frac{\Pi}{p} - \sum_{i=A,B}\frac{l_i}{l}\frac{\partial s_i^\gamma}{\partial \Pi}\frac{\Pi}{s_i^\gamma} \tag{34}$$

Proof. See Appendix. □

In the model without investment and government expenditures, the first term (the ratio of imports to consumption) basically captures the import-GDP ratio. Moreover, this model imposes trade balance, so that it also captures the export-GDP ratio. Thus, the change in the welfare depends on the trade-GDP ratio, the inflation elasticity of the terms of trade, labor shares of import and export sectors, and the inflation elasticity of the dispersion costs.

A back of the envelope calculation of the US case is used to guage the quantitative sense of the expression. It is not straightforward to divide sectors into exporting sector and importing sector, the symmetric case ($s_A = s_B$) is considered. In this case, the last term simply becomes the inflation elasticity of the dispersion cost, and the value depends on the price rigidity and other model parameters. In the case of the US, ω is 0.753, which is based on the mean frequency of price change among goods comprising producer price index (Nakamura and Steinsson, 2007). The monthly inflation rate is the rate of CPI inflation rate during their sample period, 0.25% per month. Together with (through some arbitrary calibration) $\eta = 10$ and $\gamma = 0.95$, the resource cost elasticity is 0.57. That is, a one-percent increase in the inflation rate directly reduces the welfare by 0.57%.

The terms of trade elasticity is directly calculated from the data. Using annual data compiled by OECD, the elasticity is estimated by fitting log of the terms of trade on the log of the inflation rate and several leads and lags of the first difference of the inflation rate.[23] The estimated terms of trade elasticity is 0.63. Using the trade share (the average of import and export shares) 0.11, the first term is approximately 0.069. That is, a one-percent increase in the inflation rate indirectly rises the welfare by 0.069% through improving the terms of trade. Thus, the terms of trade effect reduces welfare loss of positive inflation approximately by 12%(= 0.069/0.57).

Note that the US's trade share is the lowest among developed economies. Other things being constant, a larger trade share makes the effect of the terms of trade stronger.

4 Discussion, conclusion and future directions

Motivated by the prevalence of positive inflation rate across countries and by the cross-country, cross-industry differences in the price rigidity, this paper introduces a stylized model of nominal rigidity with trend inflation to the classical Ricardian and Ricardo-Viner international trade models. In the long-run steady state, the model implies that the magnitude of price rigidity and the inflation rate affect the pattern of trade, and that optimal inflation rate can be non-zero. The welfare loss of non-zero inflation is smaller in a two-country model than in a closed or small-open model.

The plausibility of this nominal-side driven trade theory hinges on two issues. The first issue is that the plausibility of price rigidity under a relatively high inflation rate. In the Calvo model, the frequency of price change is an exogenous parameter. However, if a country's inflation rate becomes extremely high, the price change becomes very frequent. As summarized by Klenow and Malin (2011), price rigidity is prevalent across country and time, including somewhat high (e.g., more than 5% per year) countries. Alvarez et al. (2016) study the issue of price adjustment in a high inflation environment. They examine the price rigidity of Argentina during high inflation years, and find that the frequency of price change is not large until the inflation rate becomes extremely high (say, more than 50% per year). They also provides a brief summary of the frequency of price change under high inflation episodes. Their data show that even in 10% inflation rate, the monthly frequency of price change can be less than 1/4, which means ω is more than 0.75.

The second issue is inter-sector variations in the price rigidity. If there are essentially no inter-sector differences in the price rigidity, the impact of the inflation on the sectoral productivity would be small. Nakamura and Steinsson (2008) find that wide cross-product variations in the frequency of price change in the U.S. consumer and producer price indices data. Vermeulen et al. (2012) find that

[23] The methodology obviously suffers from several issues in time series econometrics, so the values should be considered as a very rough value.

some cross-country and cross-industry variations in the frequency of price adjustment in Euro countries. Nevertheless, empirical assessment of the effect of nominal-side on the pattern of trade is an important future research topic.

The main driver of the welfare gain is the manipulation of the terms of trade. Depending on the examined country, the terms of trade effect may have a large quantitative impact. However, the existing quantitative studies of optimal inflation rate by Schmitt-Grohé and Uribe (2011) and Coibion et al. (2012) examine closed-economy cases so they do not include the effect of the terms of trade. One important research direction is to revisit the quantitative analysis of the optimal inflation rate taking the terms of trade into account. Another issue is that the gain is associated with a loss of the foreign country, as in the short-run models (e.g., Corsetti et al., 2011) or strategic tariff model (e.g., Bagwell and Staiger, 1999). A future research analyzing the strategic problem is expected.

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