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ABSTRACT

We study how trade linkages affect the conduct of monetary policy in a two-country model with heterogeneous firms, endogenous producer entry, and labor market frictions. We show that the ability of the model to replicate key empirical regularities following trade integration---synchronization of business cycles across trading partners and reallocation of market shares toward more productive firms---is central to understanding how trade costs affect monetary policy trade-offs. First, productivity gains through firm selection reduce the need of positive inflation to correct long-run distortions. As a result, lower trade costs reduce the optimal average inflation rate. Second, as stronger trade linkages increase business cycle synchronization, country-specific shocks have more global consequences. Thus, the optimal stabilization policy remains inward looking. By contrast, sub-optimal, inward-looking stabilization---for instance too narrow a focus on price stability---results in larger welfare costs when trade linkages are strong due to inefficient fluctuations in cross-country aggregate demand.

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"I would like to know how the macroeconomic model that I more or less believe can be reconciled with the trade models that I also more or less believe. [...] What we need to know is how to evaluate the microeconomics of international monetary systems. Until we can do that, we are making policy advice by the seat of our pants" (Krugman, 1995).

1 Introduction

Concern for a new era of protectionism has been making news headlines across the globe. The consequences of increasing trade barriers returned to the forefront of policy debates after the U.S. administration of President Donald Trump withdrew the U.S. from the Trans-Pacific Partnership (TPP), started renegotiating the North American Free Trade Agreement (NAFTA), and imposed punitive tariffs against a number of trading partners. Other countries expressed analogous appetite for protectionism.

In light of these recent events, a budding literature examines the macroeconomic effects of higher trade costs, both empirically and theoretically (e.g., Auray, Devereux, and Eyquem, 2019; Barattieri, Cacciatore, and Ghironi, 2018; Barbiero, Farhi, Gopinath, and Itskhoki, 2018; Erceg, Prestipino, and Raffo, 2017; Lindé and Pescatori, 2019). In contrast to this literature, the present paper studies how the strength of trade linkages affects the conduct of monetary policy both in the long run and over the business cycle.

The consequences of increased trade for incentives to cooperate across countries in monetary matters and for the desirability of alternative exchange rate arrangements are classic topics of discussion and research. In the policy arena, the implementation of the European Single Market after 1985 was viewed as a crucial step toward the adoption of the euro. The argument was that the mere possibility of exchange rate movements may eventually destabilize the Single Market, thus making monetary union desirable for the viability of a broader integration agenda (Eichengreen and Ghironi, 1996). The view that increased trade integration makes monetary cooperation—and, in this case, the adoption of a shared currency—more desirable is fully embraced in official European Union documents.[1] Influential articles by Frankel and Rose (1998) and Clark and van Wincoop (2001) provided highbrow backing for this argument by finding evidence that trade integration results in stronger business cycle comovement, thus potentially resulting in countries endogenously satisfying one of Mundell's (1961) optimum currency area criteria. At the other end of the spectrum,

[1] See "Why the euro?" (European Commission) at http://ec.europa.eu/economy_finance/euro/why/index_en.htm as of November 21, 2012.

the limited weight of international trade in U.S. GDP was often invoked among the reasons for small international spillovers to the United States, and therefore small incentives for the Federal Reserve to engage in international monetary coordination in the post-Bretton Woods era.[2] The 2007-2009 financial crisis brought global monetary cooperation to the forefront as it had not been since perhaps the Plaza Accord of 1985.

In the academic realm, researchers face important challenges when studying how trade linkages affect monetary policy tradeoffs. The reason is that benchmark international business cycle models cannot reproduce key empirical regularities about the effects of trade integration. First, workhorse models imply lack of comovement associated to stronger trade linkages, the so-called trade and comovement puzzle first documented by Kose and Yi (2001). Second, by abstracting from micro-level producer dynamics, benchmark models ignore the reallocative effects of lower trade costs across producers (Melitz, 2003, and subsequent literature). This paper shows that accounting for both features of the data is central to understanding how trade costs and trade linkages affect monetary policy trade-offs.

We develop a two-country model that incorporates the standard ingredients of the current workhorse frameworks in international trade and macroeconomics: Heterogeneous firms and endogenous producer entry in domestic and export markets (Melitz, 2003); nominal rigidity; and dynamic, stochastic, general equilibrium. Reflecting the attention of policymakers to labor market dynamics and unemployment, we introduce search-and-matching frictions in labor markets, following Diamond (1982a,b) and Mortensen and Pissarides (1994). By combining these ingredients, we answer Krugman's (1995) "call for research" that opens the paper.

We first show the model reproduces empirical regularities for the U.S. and international business cycle, including increased comovement following trade integration. In the long run, trade integration—captured by a reduction in "iceberg" trade costs (including tariffs)—results in productivity gains through firm selection, consistent with the Melitz (2003) model of trade.

We then address two main questions: (i) How do trade linkages affect the optimal average inflation target? (ii) Does trade integration change monetary policy trade-offs in response to aggregate shocks? In so doing, we evaluate whether trade linkages call for an active response to international variables and whether gains from cross-border monetary cooperation are tied to trade openness.

Three main results emerge. First, trade costs and the strength of trade linkages affect the

[2] Canzoneri and Henderson (1991) survey theoretical contributions and debates in the 1970s and 1980s. See Eichengreen and Ghironi (1998) for a discussion of the prospects for U.S.-European monetary cooperation at the outset of the euro.

optimal average inflation target. When trade costs are high (and trade linkages correspondingly weak), the optimal policy uses inflation to increase a suboptimally low job-creation, i.e., the average optimal inflation rate is positive. As lower trade costs reallocate market share toward more productive firms, the need of positive inflation to correct long-run distortions is reduced. Intuitively, the increase in average firm-level productivity pushes employment toward its efficient level, reducing the need to use average inflation to stimulate job creation.

Second, as trade linkages increase business cycle synchronization, country-specific shocks have more global consequences. Thus, the constrained efficient allocation generated by the optimal cooperative policy can be achieved by appropriately designed inward-looking policy rules even when trade linkages are strong (together with a flexible exchange rate). Put differently, as long as each central bank influences domestic distortions appropriately, increased synchronization dampens the effect of international distortions (e.g., lack of risk sharing, incentives to manipulate the terms of trade, lack of exchange rate pass-through).[3] This result echoes Benigno and Benigno's (2003) finding that only domestic distortions determine policy trade-offs when aggregate shocks (and, therefore, business cycles) are perfectly correlated across countries. Our model provides a structural microfoundation for their finding, by making increased business cycle correlation an endogenous consequence of trade integration.[4]

Third, while trade costs do not change the features of the optimal monetary stabilization policy, they affect the welfare costs of inefficient domestic stabilization. In particular, sub-optimal inward-looking policies—for instance a too narrow focus on price stability—become substantially more costly when trade linkages are strong. Intuitively, inefficient international spillovers stemming from sub-optimal fluctuations in cross-country aggregate demand result in larger welfare losses when trade linkages are stronger.

Related Literature The paper is related to the vast literature on monetary transmission and optimal monetary policy in New Keynesian macroeconomic models.[5] We contribute to the strand of this literature that incorporates labor market frictions, such as Arseneau and Chugh (2008), Faia (2009), and Thomas (2008), and to the literature on price stability in open economies (Benigno and Benigno, 2003 and 2006, Catão and Chang, 2013, Galí and Monacelli, 2005, Dmitriev and

[3] With weak trade linkages, international distortions have second-order welfare effects; when trade linkages are strong, they are not more costly (if inward-looking policies are designed optimally) because of increased comovement.

[4] An implication of this result is that the gains from optimal cooperation remain modest compared to optimal, non-cooperative policy.

[5] See Corsetti, Dedola, and Leduc (2010), Galí (2008), Schmitt-Grohé and Uribe (2010), Walsh (2010), Woodford (2003), and references therein.

Hoddenbagh, 2012, and many others) by studying hitherto unexplored mechanisms that affect monetary policy incentives.

A recent New Keynesian literature has made an effort to incorporate trade integration among the determinants of policy incentives. The main focus of this literature is the relationship between trade openness and optimal exchange rate volatility, where openness is defined by changes in the degree of home bias in consumer preferences and/or the weight of imported inputs in production.[6] While there is undisputed merit in this exercise, proxying a policy outcome (the extent of trade integration) with structural parameters of preferences and technology risks confounding the consequences of a policy change (the removal—or lowering—of trade barriers) with those of features of agents' behavior that may have little to do with policy. Moreover, these studies abstract from the effects of business cycle synchronization and trade-induced reallocation of shares reallocation.

The paper is also related to Bergin and Corsetti (2018), who study the relationship between monetary policy and the composition of international trade. They show that (efficient) monetary stabilization policy can lead a country to specialize in relatively more differentiated industries, where demand and marginal costs are more sensitive to macroeconomic uncertainty. Our study explores an alternative channel through which monetary policy affects external competitiveness. In the presence of firm heterogeneity, monetary policy affects export entry decisions along the extensive margin of trade within a given industry. As a result, domestic policy can optimally increase the number of manufacturing producers that also export, in addition to selling domestically, boosting the external competitiveness of the country.

Finally, our paper contributes to the literature that studies how endogenous entry and product variety affect business cycles and optimal policy in closed and open economies. In this literature, our work is most closely related to Cacciatore (2014), who studies how labor market frictions affect the consequences of trade integration in a real model that merges Ghironi and Melitz (2005) with the Diamond-Mortensen-Pissarides framework. His analysis shows that search-and-matching frictions, firm heterogeneity, and endogenous producer entry are key ingredients to address the trade comovement puzzle. We introduce sticky prices and wages in Cacciatore's model and study how trade integration affects monetary policy. Our results on optimal monetary policy extend those in Bilbiie, Fujiwara, and Ghironi (2014—BFG) and Cacciatore, Fiori, and Ghironi (2016): As in BFG, an inefficiency wedge in product creation is among the reasons for the Ramsey central bank of

[6] See, for instance, Coenen, Lombardo, Smets, and Straub (2007), Faia and Monacelli (2008), and Lombardo and Ravenna (2014).

our to use positive long-run inflation, but our model features a wider menu of sources of inefficiency, with the labor margin affected by a larger number of distortions. Differently from BFG, we find that the interaction of distortions in our model can result in sizable, optimal departures from price stability over the business cycle. In this respect, our approach and results are closer to the analysis of market deregulation and optimal monetary policy in a monetary union in Cacciatore, Fiori, and Ghironi (2016), whose model, however, does not incorporate the firm heterogeneity and reallocation effects that are central to the recent trade literature.[7]

2 The Model

We model an economy that consists of two countries, Home and Foreign. Foreign variables are denoted with a superscript star. We focus on the Home economy in presenting our model, with the understanding that analogous equations hold for Foreign. We resort to a cashless economy following Woodford (2003).

Household Preferences

Each country is populated by a unit mass of atomistic households, where each household is thought of as an extended family with a continuum of members along the unit interval. In equilibrium, some family members are unemployed, while some others are employed. As common in the literature, we assume that family members perfectly insure each other against variation in labor income due to changes in employment status, so that there is no *ex post* heterogeneity across individuals in the household (see Andolfatto, 1996, and Merz, 1995).

The representative household in the Home economy maximizes the expected intertemporal utility function $E_0 \sum_{t=0}^{\infty} \beta^t [u(C_t) - l_t v(h_t)]$, where $\beta \in (0, 1)$ is the discount factor, C_t is a consumption basket that aggregates domestic and imported goods as described below, l_t is the number of employed workers, and h_t denotes hours worked by each employed worker. Period utility from consumption, $u(\cdot)$, and disutility of effort, $v(\cdot)$, satisfy the standard assumptions.

The consumption basket C_t aggregates Home and Foreign sectoral consumption outputs $C_t(i)$ in Dixit-Stiglitz form: $C_t = \left[\int_{i \in \Omega} C_t(i)^{(\phi-1)/\phi} di\right]^{\phi/(\phi-1)}$, where $\phi > 1$ is the symmetric elasticity of substitution across goods. A similar basket describes consumption in the Foreign country. The

[7] On optimal policy with endogenous producer entry, see also Bergin and Corsetti (2008), Chugh and Ghironi (2011), and Lewis (2013), among others. Auray and Eyquem (2011) and Cavallari (2013) study the role of monetary policy for shocks transmission in two-country versions of Bilbiie, Ghironi, and Melitz's (2012) model, but they do not analyze optimal monetary policy.

corresponding consumption-based price index is given by: $P_t = \left[\int_{i\in\Omega} P_t(i)^{1-\phi} di\right]^{1/(1-\phi)}$, where $P_t(i)$ is the price index for sector i, expressed in Home currency.

Production

In each country, there are two vertically integrated production sectors. In the upstream sector, perfectly competitive firms use labor to produce a non-tradable intermediate input. In the downstream sector, each consumption-producing sector is populated by a representative monopolistically-competitive multi-product firm that purchases intermediate input and produces differentiated varieties. In equilibrium, some of these varieties are exported while the others are sold only domestically.[8]

Intermediate Goods Production

There is a unit mass of symmetric intermediate producers. Each of them employs a continuum of workers. Labor markets are characterized by search and matching frictions. To hire new workers, firms need to post vacancies, incurring a cost of κ units of consumption per vacancy posted. The probability of finding a worker depends on a constant-return-to-scale matching technology, which converts aggregate unemployed workers, U_t, and aggregate vacancies, V_t, into aggregate matches, $M_t = \chi U_t^{1-\varepsilon} V_t^{\varepsilon}$, where $\chi > 0$ and $0 < \varepsilon < 1$. Each firm meets unemployed workers at a rate $q_t \equiv M_t/V_t$. As in Krause and Lubik (2007) and other studies, we assume that newly created matches become productive only in the next period. For an individual firm, the inflow of new hires in $t+1$ is therefore $q_t \upsilon_t$, where υ_t is the number of vacancies posted by the firm in period t. In equilibrium, $\upsilon_t = V_t$.

Firms and workers can separate exogenously with probability $\lambda \in (0,1)$. Separation happens only between firms and workers who were active in production in the previous period. As a result the law of motion of employment in a given firm, l_t, is given by $l_t = (1-\lambda) l_{t-1} + q_{t-1}\upsilon_{t-1}$.

As in Arsenau and Chugh (2008), firms face a quadratic cost of adjusting the hourly nominal wage rate, w_t. For each worker, the real cost of changing the nominal wage between period $t-1$ and t is $\vartheta \pi_{w,t}^2/2$, where $\vartheta \geq 0$ is in units of consumption, and $\pi_{w,t} \equiv (w_t/w_{t-1}) - 1$ is the net wage inflation rate. If $\vartheta = 0$, there is no cost of wage adjustment. The representative intermediate firm produces output $y_t^I = Z_t l_t h_t$, where Z_t is exogenous aggregate productivity. We assume the

[8] This production structure greatly simplifies the introduction of nominal rigidities in the model.

following bivariate process for Home and Foreign productivity:

$$\begin{bmatrix} \log Z_t \\ \log Z_t^* \end{bmatrix} = \begin{bmatrix} \phi_{11} & \phi_{12} \\ \phi_{21} & \phi_{22} \end{bmatrix} \begin{bmatrix} \log Z_{t-1} \\ \log Z_{t-1}^* \end{bmatrix} + \begin{bmatrix} \epsilon_t \\ \epsilon_t^* \end{bmatrix},$$

where ϕ_{11} and ϕ_{22} are strictly between 0 and 1, and ϵ_t and ϵ_t^* are normally distributed innovations with variance-covariance matrix $\Sigma_{\epsilon,\epsilon^*}$.

Intermediate-goods producers sell their output to final producers at a real price φ_t in units of consumption. Intermediate producers choose the number of vacancies, υ_t, and employment, l_t, to maximize the expected present discounted value of their profit stream:

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{u_{C,t}}{u_{C,0}} \left(\varphi_t Z_t l_t h_t - \frac{w_t}{P_t} l_t h_t - \kappa \upsilon_t - \frac{\vartheta}{2} \pi_{w,t}^2 l_t \right),$$

where $u_{C,t}$ denotes the marginal utility of consumption in period t, subject to the law of motion of employment. Future profits are discounted with the stochastic discount factor of domestic households, who are assumed to own Home firms.

Combining the first-order conditions for vacancies and employment yields the following job creation equation:

$$\frac{\kappa}{q_t} = E_t \left\{ \beta_{t,t+1} \left[(1-\lambda) \frac{\kappa}{q_{t+1}} + \varphi_{t+1} Z_{t+1} h_{t+1} - \frac{w_{t+1}}{P_{t+1}} h_{t+1} - \frac{\vartheta}{2} \pi_{w,t+1}^2 \right] \right\}, \tag{1}$$

where $\beta_{t,t+1} \equiv \beta u_{C,t+1}/u_{C,t}$ is the one-period-ahead stochastic discount factor. The job creation condition states that, at the optimum, the vacancy creation cost incurred by the firm per current match is equal to the expected discounted value of the vacancy creation cost per future match, further discounted by the probability of current match survival $1 - \lambda$, plus the profits from the time-t match. Profits from the match take into account the future marginal revenue product from the match and its wage cost, including future nominal wage adjustment costs.

Wage and Hours The nominal wage is the solution of an individual Nash bargaining process, and the wage payment divides the match surplus between workers and firms. We present the details of wage determination in Appendix A. We show there the equilibrium sharing rule can be written as $\eta_t H_t = (1 - \eta_t) J_t$, where η_t is the bargaining share of firms, H_t is worker surplus, and J_t is firm surplus (see Appendix A for the analytical expressions). As in Gertler and Trigari (2009), the bargaining share is time-varying due to the presence of wage adjustment costs. Absent these costs, we would have a time-invariant bargaining share $\eta_t = \eta$, where η is the weight of firm surplus in the Nash bargaining problem.

The bargained wage satisfies:

$$\begin{aligned} \frac{w_t}{P_t} h_t &= \eta_t \left(\frac{v(h_t)}{u_{C,t}} + b \right) + (1 - \eta_t) \left(\varphi_t Z_t h_t - \frac{\vartheta}{2} \pi_{w,t}^2 \right) \\ &+ E_t \left\{ \beta_{t,t+1} J_{t+1} \left[(1 - \lambda)(1 - \eta_t) - (1 - \lambda - \iota_t)(1 - \eta_{t+1}) \frac{\eta_t}{\eta_{t+1}} \right] \right\}, \end{aligned} \tag{2}$$

where $v(h_t)/u_{C,t} + b$ is the worker's outside option (the utility value of leisure in consumption units plus an unemployment benefit b), and ι_t is the probability of becoming employed at time t, defined by $\iota_t \equiv M_t/U_t$. With flexible wages, the third term in the right-hand side of this equation reduces to $(1 - \eta)\, \iota_t E_t \left(\beta_{t,t+1} J_{t+1} \right)$, or, in equilibrium, $\kappa\,(1 - \eta)\, \iota_t/q_t$. In this case, the real wage is a linear combination—determined by the constant bargaining parameter η—of the worker's outside option and the marginal revenue product generated by the worker plus the expected discounted continuation value of the match to the firm (adjusted for the probability of worker's employment). When wages are sticky, bargaining shares are endogenous, and so is the distribution of surplus between workers and firms. Moreover, the current wage bill reflects also expected changes in bargaining shares.

As common practice in the literature we assume that hours per worker are determined by firms and workers in a privately efficient way, i.e., so as to maximize the joint surplus of their employment relation. The joint surplus is the sum of the firm's surplus and the worker's surplus, i.e., $J_t + H_t$. Maximization yields a standard intratemporal optimality condition for hours worked that equates the marginal revenue product of hours per worker to the marginal rate of substitution between consumption and leisure: $v_{h,t}/u_{C,t} = \varphi_t Z_t$, where $v_{h,t}$ is the marginal disutility of effort.

Final Goods Production

In each consumption sector i, a representative multi-product firm produces a differentiated bundle $Y_t(i)$ sold to consumers in Home and Foreign. The bundle $Y_t(i)$ consists of differentiated product varieties, indexed by ω and defined over a continuum Ω: $Y_t(i) = \left(\int_{\omega \in \Omega}^{\infty} y_t(\omega, i)^{(\theta-1)/\theta} d\omega \right)^{\theta/(\theta-1)}$, where $\theta > 1$ is the symmetric elasticity of substitution across product varieties.[9]

Each product variety $y(\omega, i)$ is created and developed by the representative final producer i.

[9] Sectors (and sector-representative firms) are of measure zero relative to the aggregate size of the economy. Notice that $Y_t(i)$ can also be interpreted as a bundle of product features that characterize the final product i.

Since consumption-producing sectors are symmetric, from now on we omit the index i to simplify notation. The nominal cost of the product bundle Y_t is: $\varphi^n_{Y,t} = \left(\int_{\omega\in\Omega}^{\infty} \varphi^n_t(\omega)^{1-\theta} d\omega\right)^{1/(1-\theta)}$, where $\varphi^n_t(\omega)$ is the nominal marginal cost of producing variety ω.

The number of products (or features) created and commercialized by each final producer is endogenous. At each point in time, only a subset of varieties $\Omega_t \subset \Omega$ is actually available to consumers. To create a new product, the final producer needs to undertake a sunk investment, $f_{E,t}$, in units of intermediate input. Product creation requires the creation of a new plant that will be producing the new variety.[10] Plants produce with different technologies indexed by relative productivity z. To save notation, we identify a variety with the corresponding plant productivity z, omitting ω. Upon product creation, the productivity level of the new plant z is drawn from a common distribution $G(z)$ with support on $[z_{\min}, \infty)$. Foreign plants draw productivity levels from an identical distribution. This relative productivity level remains fixed thereafter. Each plant uses the intermediate input to produce its differentiated product variety, with real marginal cost: $\varphi_{z,t} = \varphi_t/z$.

At time t, each final Home producer commercializes $N_{D,t}$ varieties and creates $N_{E,t}$ new products that will be available for sale at time $t+1$. New and incumbent plants can be hit by a "death" shock with probability $\delta \in (0,1)$ at the end of each period. The law of motion for the stock of producing plants is $N_{D,t+1} = (1-\delta)(N_{D,t} + N_{E,t})$.

When serving the Foreign market, each final producer faces per-unit iceberg trade costs, $\tau_t > 1$, and fixed export costs, $f_{X,t}$. Following Ghironi and Melitz (2005), fixed export costs are denominated in units of intermediate input and paid for each exported product. Thus, the total fixed cost is $N_{X,t}f_{X,t}$, where $N_{X,t}$ denotes the number of product varieties exported to Foreign. Absent fixed export costs, each producer would sell all its product varieties in Home and Foreign. Fixed export costs imply that only varieties produced by plants with sufficiently high productivity (above a cutoff level $z_{X,t}$, determined below) are exported.[11]

Define two special "average" productivity levels (weighted by the relative output shares): an average $\tilde{z}_D$ for all producing plants and an average $\tilde{z}_{X,t}$ for all the plants that export:

$$\tilde{z}_D = \left[\int_{z_{\min}}^{\infty} z^{\theta-1} dG(z)\right]^{\frac{1}{\theta-1}}, \qquad \tilde{z}_{X,t} = \left[\frac{1}{1-G(z_{X,t})}\right]\left[\int_{z_{X,t}}^{\infty} z^{\theta-1} dG(z)\right]^{\frac{1}{\theta-1}}. \tag{3}$$

[10] Alternatively, we could decentralize product creation by assuming that monopolistically competitive firms produce product varieties (or features) that are sold to final producers, in this case interpreted as retailers. The two models are isomorphic. Details are available upon request.

[11] Notice that $z_{X,t}$ is the lowest level of plant productivity such that the profit from exporting is positive.

Assume that $G(\cdot)$ is Pareto with shape parameter $k_p > \theta - 1$. As a result, $\tilde{z}_D = \alpha^{1/(\theta-1)} z_{\min}$ and $\tilde{z}_{X,t} = \alpha^{1/(\theta-1)} z_{X,t}$, where $\alpha \equiv k_p / (k_p - \theta + 1)$. The share of exporting plants is given by:

$$\frac{N_{X,t}}{N_{D,t}} \equiv 1 - G(z_{X,t}) = \left(\frac{z_{\min}}{\tilde{z}_{X,t}}\right)^{-k_p} \alpha^{\frac{k_p}{\theta-1}} N_{D,t}. \tag{4}$$

The output bundle for domestic sales is $Y_{D,t} = \left[\int_{z_{\min}}^{\infty} y_{D,t}(z)^{(\theta-1)/\theta} dG(z)\right]^{\theta/(\theta-1)}$, while the export bundle is $Y_{X,t} = \left[\int_{z_{X,t}}^{\infty} y_{X,t}(z)^{(\theta-1)/\theta} dG(z)\right]^{\theta/(\theta-1)}$. The nominal unit costs of production for the domestic and export bundles are, respectively: $\varphi_{D,t}^n = \left[\int_{z_{\min}t}^{\infty} \varphi_t^n(z)^{1-\theta} dG(z)\right]^{1/(1-\theta)}$ and $\varphi_{X,t}^n = \left[\int_{z_{X,t}}^{\infty} \varphi_t^n(z)^{(\theta-1)/\theta} dG(z)\right]^{1/(1-\theta)}$. In turn, using (3), the real costs of producing $Y_{D,t}$ and $Y_{X,t}$ are given by:

$$\varphi_{D,t} \equiv \frac{\varphi_{D,t}^n}{P_t} = N_{D,t}^{\frac{1}{1-\theta}} \frac{\varphi_t}{\tilde{z}_D}, \qquad \varphi_{X,t} \equiv \frac{\varphi_{X,t}^n}{P_t} = N_{X,t}^{\frac{1}{1-\theta}} \frac{\varphi_t}{\tilde{z}_{X,t}}. \tag{5}$$

The producer determines $N_{D,t+1}$ and the productivity cutoff $z_{X,t}$ to minimize its expected total present discounted cost of production:

$$E_t \sum_{s=t}^{\infty} \beta_{t,s} \left[\varphi_{D,s} Y_{D,s} + \tau_s \varphi_{X,s} Y_{X,s} + \left(\frac{N_{s+1}}{1-\delta} - N_s\right) f_{E,s} \varphi_s + N_{X,s} f_{X,s} \varphi_s\right],$$

subject to (4), (5), and $\tilde{z}_{X,t} = \alpha^{1/(\theta-1)} z_{X,t}$. The first-order condition with respect to $z_{X,t}$ yields:

$$\frac{k_p - (\theta-1)}{(\theta-1)k_p} \tau_t \varphi_{X,t} Y_{X,t} = f_{X,t} \varphi_t N_{X,t}.$$

At the optimum, the marginal revenue from adding a variety with productivity $z_{X,t}$ to the export bundle has to be equal to the fixed cost. Thus, varieties produced by plants with productivity below $z_{X,t}$ are distributed only in the domestic market. The set of exported products fluctuates over time with changes in the profitability of export.

The first-order condition with respect to $N_{D,t+1}$ determines product creation:

$$\varphi_t f_{E,t} = E_t \left\{ (1-\delta) \beta_{t,t+1} \left[\begin{array}{c} \varphi_{t+1} \left(f_{E,t+1} - \frac{N_{X,t+1}}{N_{D,t+1}} f_{X,t+1} \right) \\ + \frac{1}{\theta-1} \left(\varphi_{D,t+1} \frac{Y_{D,t+1}}{N_{D,t+1}} + \tau_{t+1} \varphi_{X,t+1} \frac{Y_{X,t+1}}{N_{X,t+1}} \frac{N_{X,t+1}}{N_{D,t+1}} \right) \end{array} \right] \right\}.$$

At the optimum, the cost of producing an additional variety, $\varphi_t f_{E,t}$, must be equal to its expected benefit (which includes expected savings on future sunk investment costs augmented by the marginal revenue from commercializing the variety, net of fixed export costs, if it is exported).

We are now left with the determination of domestic and export prices. Denote with $P_{D,t}$ the price (in Home currency) of the product bundle $Y_{D,t}$ and let $P_{X,t}$ be the price (in Foreign currency) of the exported bundle $Y_{X,t}$. Each final producer faces the following domestic and foreign demand for its product bundles: $Y_{D,t} = (P_{D,t}/P_t)^{-\phi} Y_t^C$ and $Y_{X,t} = (P_{X,t}/P_t^*)^{-\phi} Y_t^{C*}$, where Y_t^C and Y_t^{C*} are aggregate demands of the consumption basket in Home and Foreign.[12]

Prices in the final sector are sticky. We follow Rotemberg (1982) and assume that final producers must pay quadratic price adjustment costs when changing domestic and export prices. In the benchmark version of the model, we consider producer currency pricing (PCP). Absent fixed export costs, the producer would set a single price $P_{D,t}$ and the law of one price (adjusted for the presence of trade costs) would determine the export price. However, with fixed export costs, the composition of the domestic and export bundles is different, and the marginal costs of producing these bundles are not equal. Therefore, final producers choose two different prices for the Home and Foreign markets. Under PCP, each producer sets $P_{D,t}$ and the domestic currency price of the export bundle, $P_{X,t}^h$. In turn, the price in the foreign market is $P_{X,t} = P_{X,t}^h/S_t$, where S_t denotes the nominal exchange rate. The nominal costs of adjusting domestic and export price are, respectively, $\Gamma_{D,t} \equiv \nu\pi_{D,t}^2 P_{D,t} Y_{D,t}/2$, and $\Gamma_{X,t}^h \equiv \nu\pi_{X,t}^{h2} P_{X,t}^h Y_{X,t}/2$, where $\nu \geq 0$ determines the size of the adjustment costs, $\pi_{D,t} = (P_{D,t}/P_{D,t-1} - 1)$, and $\pi_{X,t}^h = (P_{X,t}^h/P_{X,t-1}^h - 1)$.

As shown in Appendix B, the real price of Home output for domestic sales is given by: $\rho_{D,t} \equiv P_{D,t}/P_t = \mu_{D,t}\varphi_{D,t}$, where $\mu_{D,t}$ denotes the time-varying domestic markup. The real price of Home output for export sales, $\rho_{X,t}^h \equiv P_{X,t}^h/P_t$, is $\rho_{X,t}^h = \tau_t \mu_{X,t}^h \varphi_{X,t}$, where $\mu_{X,t}^h$ denotes the export markup. (See Appendix B for the analytical expressions for $\mu_{D,t}$ and $\mu_{X,t}^h$). As expected, the cost of adjusting prices gives firms an incentive to change their markups over time in order to smooth price changes across periods. When prices are flexible, $\mu_{D,t} = \mu_{X,t}^h = \phi/(\phi - 1)$. In addition, $z_{X,t} = z_{\min}$ and $\mu_{D,t} = \mu_{X,t}^h$ absent fixed export costs. Let $Q_t \equiv SP_t^*/P_t$ be the consumption-based real exchange rate (units of Home consumption per units of Foreign) and recall that $P_{X,t}^h = S_t P_{X,t}$ under producer currency pricing. The optimal export price in units of foreign consumption is given by: $\rho_{X,t} \equiv P_{X,t}/P_t^* = \tau_t \mu_{X,t}^h \varphi_{X,t}/Q_t$.

Define the average price of a domestic variety, $\tilde{\rho}_{D,t} \equiv N_{D,t}^{1/(\theta-1)} \rho_{D,t}$ and the average price of

[12] Aggregate demand in each country includes sources other than household consumption, but it takes the same form as the consumption basket, with the same elasticity of substitution $\phi > 1$ across sectoral bundles.

an exported variety, $\tilde{\rho}_{X,t} \equiv N_{X,t}^{1/(\theta-1)} \rho_{X,t}$. Using the above results, $\tilde{\rho}_{D,t} = \mu_{D,t}\varphi_t/\tilde{z}_D$ and $\tilde{\rho}_{X,t} = \mu^h_{X,t} (\tau_t/Q_t) (\varphi_t/\tilde{z}_{X,t})$. Finally, let $\tilde{y}_{D,t} \equiv \tilde{\rho}_{D,t}^{-\phi} N_{D,t}^{(\theta-\phi)/(1-\theta)} Y_t^C$ and $\tilde{y}_{X,t} \equiv \tilde{\rho}_{X,t}^{-\phi} N_{X,t}^{(\theta-\phi)/(1-\theta)} Y_t^{C*}$ denote the average output of a domestic and exported variety, respectively.

To summarize, the assumption of price rigidity at the bundle level preserves the aggregation properties of the original Melitz (2003) model in the presence of nominal price rigidities. A consequence of our assumption is that price changes are fully synchronized across products within a firm.[13] This is consistent with the evidence in Bhattarai and Schoenley (2014), who document substantial synchronization of price changes within firms across goods. The different composition of domestic and exported bundles is also consistent with the evidence in Dvir and Strasser (2018).

Household Budget Constraint and Intertemporal Decisions

International assets markets are incomplete as only risk-free bonds are traded across countries. Home bonds, issued by Home households, are denominated in Home currency. Foreign bonds, issued by Foreign households, are denominated in Foreign currency. Let A_{t+1} and $A_{*,t+1}$ (A_t^* and $A_{*,t}^*$) denote, respectively, nominal holdings of Home and Foreign bonds at Home (Foreign). To induce steady-state determinacy and stationary responses to temporary shocks in the model, we assume a quadratic cost of adjusting bond holdings (e.g., Turnovsky, 1985). The cost of adjusting Home bond holdings is $\psi \left(A_{t+1}/P_t\right)^2/2$, while the cost of adjusting Foreign bond holdings is $\psi \left(A_{*,t+1}/P_t^*\right)^2/2$. These costs are paid to financial intermediaries who rebate the revenue to households in lump-sum fashion.

The Home household's budget constraint is:

$$A_{t+1} + S_t A_{*,t+1} + \frac{\psi}{2} P_t \left(\frac{A_{t+1}}{P_t}\right)^2 + \frac{\psi}{2} S_t P_t^* \left(\frac{A_{*,t+1}}{P_t^*}\right)^2 + P_t C_t =$$
$$= (1+i_t)A_t + (1+i_t^*)A_{*,t}S_t + w_t l_t + P_t b(1-l_t) + T_t^g + T_t^A + T_t^i + T_t^f,$$

where i_{t+1} and i_{t+1}^* are, respectively, the nominal interest rates on Home and Foreign bond holdings between t and $t+1$, known with certainty as of $t-1$. Moreover, T_t^g is a lump-sum transfer (or tax) from the government, T_t^A is a lump-sum rebate of the cost of adjusting bond holdings from the intermediaries, and T_t^i and T_t^f are lump-sum profits rebate from intermediate and final goods producers.

[13] Within the representative multi-product firm, the price ratio between any pair of products in a given market is constant and equal to the inverse of the ratio of plant-specific productivities.

Let $a_{t+1} \equiv A_{t+1}/P_t$ denote real holdings of Home bonds (in units of Home consumption) and let $a_{*,t+1} \equiv A_{*,t+1}/P_t^*$ denote real holdings of Foreign bonds (in units of Foreign consumption). The Euler equation for domestic bond holdings implies $1+\psi a_{t+1} = (1+i_{t+1}) E_t \left[\beta_{t,t+1} (1+\pi_{C,t+1})^{-1}\right]$, where $\pi_{C,t} \equiv (P_t/P_{t-1}) - 1$ denotes Home CPI inflation. The Euler equation for Foreign bond holdings is $1+\psi a_{*t+1} = \left(1+i_{t+1}^*\right) E_t \left\{\beta_{t,t+1} Q_{t+1} \left[Q_t \left(1+\pi_{C,t+1}^*\right)\right]^{-1}\right\}$.

Net Foreign Assets and the Trade Balance

We present the details of the model equilibrium in Appendix C. Here we limit ourselves to presenting the law of motion for net foreign assets below. Bonds are in zero net supply, which implies the equilibrium conditions $a_{t+1} + a_{t+1}^* = 0$ and $a_{*,t+1}^* + a_{*,t+1} = 0$ in all periods. Net foreign assets are determined by:

$$a_{t+1} + Q_t a_{*,t+1} = \frac{1+i_t}{1+\pi_{C,t}} a_t + Q_t \frac{1+i_t^*}{1+\pi_{C,t}^*} a_{*,t} + TB_t.$$

where $TB_t \equiv Q_t N_{X,t} \tilde{\rho}_{X,t} \tilde{y}_{X,t} - N_{X,t}^* \tilde{\rho}_{X,t}^* \tilde{y}_{X,t}^*$ is the trade balance.

3 Monetary Policy

In our benchmark exercise, we compare the Ramsey-optimal, cooperative monetary policy to the consequences of historical behavior by the Federal Reserve and its symmetric counterpart under a flexible exchange rate. Following Sims (2007), we consider historical behavior a more realistic benchmark for comparison than optimal, non-cooperative policies.

Data-Consistent Variables and Historical Monetary Policy

Historical policy is captured by a standard rule for interest rate setting for both central banks. Before describing the interest-rate setting rule that characterizes historical policy, we must address an issue that concerns the data that are actually available to the central bank. Since gains from variety are mostly unmeasured in CPI data (Broda and Weinstein, 2010), we construct a data-consistent price index, $\tilde{P}_t$, that removes the product-variety effect from the welfare-consistent index P_t.[14] Following Ghironi and Melitz (2005), we define the average price index as $\tilde{P}_t \equiv \left(N_{D,t} + N_{X,t}^*\right)^{1/(\theta-1)} P_t$. In turn, given any variable X_t in units of consumption, its data-consistent counterpart is $X_{R,t} \equiv X_t P_t/\tilde{P}_t = X_t \left(N_{D,t} + N_{X,t}^*\right)^{1/(\theta-1)}$.

[14] In the presence of endogenous producer entry and preferences that exhibit "love for variety," the welfare-consistent aggregate price index P_t can fluctuate even if product prices remain constant.

Each country's central bank sets its interest rate to respond to data-consistent CPI inflation, $\tilde{\pi}_{C,t}$, and GDP gap, $\tilde{Y}_{g,t}$, relative to the equilibrium with flexible prices and wages:[15]

$$1 + i_{t+1} = (1 + i_t)^{\varrho_i} \left[(1 + i) (1 + \tilde{\pi}_{C,t})^{\varrho_\pi} \left(\tilde{Y}_{g,t} \right)^{\varrho_Y} \right]^{1-\varrho_i} . \quad (6)$$

An analogous rule for interest rate setting applies to Foreign.

Ramsey-Optimal, Cooperative Monetary Policy

The Ramsey authority maximizes aggregate welfare

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{1}{2} [u(C_t) - l_t v(h_t)] + \frac{1}{2} [u(C_t^*) - l_t^* v(h_t^*)] \right\}, \quad (7)$$

under the constraints of the competitive economy (see Appendix D for the full set of equilibrium conditions). As common practice in the literature, we write the original non-stationary Ramsey problem in a recursive stationary form by enlarging the planner's state space with additional (pseudo) co-state variables. Such co-state variables track the value to the planner of committing to the pre-announced policy plan along the dynamics.

4 Calibration

We interpret periods as quarters and calibrate the model to match U.S. macroeconomic data. Table 1 summarizes the calibration, which is assumed symmetric across countries. (Variables without time indexes denote steady-state levels.) We set the discount factor β to 0.99 and assume the following period utility function: $u_t = C_t^{1-\gamma_C}/(1-\gamma_C) - l_t h_t^{1+\gamma_h}/(1+\gamma_h)$. The risk aversion coefficient γ_C is equal to 1, while the Frisch elasticity of labor supply $1/\gamma_h$ is set to 0.25, a mid-point between empirical micro and macro estimates.[16] Following Ghironi and Melitz (2005), we set the elasticity of substitution across product varieties, θ, and the elasticity of substitution across Home and Foreign goods, ϕ, equal to 3.8. As in Ghironi and Melitz (2005), we also set $k_p = 3.4$, normalize $z_{\min}$ to 1, and calibrate the fixed export cost f_X so that the share of exporting plants is equal to 21 percent.

[15] We define GDP as total income: the sum of labor income, dividend income from final producers, and profit income from intermediate producers. Formally: $GDP_t \equiv (w_t/P_t)\, l_t + \left(T_t^f - \varphi_t N_{e,t} f_{e,t} \right) + T_t^i$.

[16] Students of the business cycle tend to work with elasticities that are higher than microeconomic estimates, typically unity and above. Most microeconomic studies, however, estimate this elasticity to be much smaller, between 0.1 and 0.6. Our results are not affected significantly if we hold hours constant at the optimally determined steady-state level.

We choose iceberg trade costs, τ, so that total trade (imports plus exports) over GDP is equal to 10 percent, the average value for the U.S. over the period 1954-1980.[17] This requires setting $\tau - 1 = 1.47$, consistent with the estimates of trade costs reported by Anderson and van Wincoop (2003).

We set the bond adjustment cost ψ to 0.0025 as in Ghironi and Melitz (2005). The scale parameter for the cost of adjusting prices, ν, is equal to 80, following Bilbiie, Ghironi, and Melitz (2008). We choose ϑ, the scale parameter of nominal wage adjustment costs, so that the model reproduces the volatility of unemployment relative to GDP observed in the data. This implies setting $\vartheta = 290$. To calibrate the entry costs, we follow Ebell and Haefke (2009) and set f_E so that regulation costs amount to 5.2 months of per capita output.

We set unemployment benefits, b, so that the model reproduces the average replacement rate, $b/(wh)$, for the U.S. reported by OECD (2004). The steady-state bargaining share of firms, η, is equal to 0.6, as estimated by Flinn (2006) for the U.S. The elasticity of the matching function, ε, is also equal to 0.6, within the range of estimates reported by Petrongolo and Pissarides (2006) and such that the Hosios condition holds in steady state. The quarterly exogenous separation rate between firms and workers, λ, is 10 percent, as in Shimer (2005). We calibrate the cost of vacancy posting, κ, and the matching efficiency parameter, χ, to match the steady-state probability of finding a job and the probability of filling a vacancy. The former is 75 percent, while the latter is 70 percent, in line with Shimer (2005). To pin down the exogenous producer exit rate, δ, we assume that job destruction due to plant exit is equal to 40 percent (Haltiwanger, Scarpetta, and Schweiger, 2008).

For the bivariate productivity process, we set persistence and spillover parameters consistent with the evidence in Baxter and Farr (2005), implying zero spillovers across countries and persistence equal to 0.999. Moreover, we set the standard deviation of productivity innovations at 0.73 percent and the covariance of innovations at 0.19 percent, as in Backus, Kehoe, and Kydland (1992). Finally, the parameter values in the historical rule for the Fed's interest rate setting are those estimated by Clarida, Galí and Gertler (2000). The inflation and GDP gap weights are 1.62 and 0.34, respectively, while the smoothing parameter is 0.71.

[17] This time period featured relatively weak trade linkages between the U.S. economy and the rest of the world. The growth in U.S. trade began at the beginning of the 80's, experiencing a five-fold growth in nominal terms over the next twenty five years— in 1980 US two-way merchandise trade was 467 billion U.S. dollars, reaching 2,942 billion U.S. dollars in 2006 (UNComtrade via WITS 2008).

Model Properties In Appendix E, we present the second-moment properties of the model under the historical policy, showing the model successfully replicates several features of the U.S. and international business cycle. Here we briefly discuss the propagation of a positive productivity shock. Figure 1 (solid lines) shows impulse responses to a one-percent innovation to Home productivity under the historical rule for the Fed interest rate setting. The higher expected return of a match induces domestic intermediate input producers to post more vacancies on impact, which results in higher employment in the following period. Firms and workers (costly) renegotiate nominal wages because of the higher surplus generated by existing matches, and wage inflation increases. Wage adjustment costs make the effective firm's bargaining power procyclical, i.e., η_t rises. Other things equal, the increase in η_t dampens the response of the renegotiated equilibrium wage, amplifying the response of job creation to the shock.

Higher employment and labor income boost aggregate demand for final goods and consumption. The larger present discounted value of future profits generates higher product creation and investment at Home. The number of domestic plants that produce for the export market also increases, since higher aggregate productivity reduces the export productivity cutoff $z_{X,t}$. In turn, the endogenous selection of relatively low-productive firms into the export market partially offsets the reduction in marginal costs and export prices generated by higher aggregate productivity, since $\varphi_{X,t} = \varphi_t/\tilde{z}_{X,t}$. Thus, the terms of trade ($TOT_t \equiv S_t P_{X,t}/P^*_{X,t}$) fall less relative to a model that abstracts from plant heterogeneity.

Foreign households shift resources to Home to finance product creation in the more productive economy. Accordingly, Home runs a current account deficit in response to the shock. At the same time, GDP, employment, and investment comove positively across countries. The increase in aggregate demand at Home (which falls on both domestic and imported goods) and the moderate size of expenditure switching effects induced by terms-of-trade dynamics explain this result (see also Cacciatore, 2014).

5 Optimal Monetary Policy with Weak Trade Linkages

We begin by discussing the Ramsey-optimal monetary policy when trade linkages are weak. First, we study optimal monetary policy in the long run, then we turn to the Ramsey allocation over the business cycle.

Optimal Monetary Policy in the Long Run

Our interest in this section is in how the two Ramsey central banks determine the optimal inflation rates π_C and π^*_C. To begin, it is immediate to verify that long-run inflation is always symmetric across countries regardless of symmetry or asymmetry of the calibration. This result follows from the Euler equations for bond holdings once it is observed that the latter are always zero in steady state: $1 + \pi_C = \beta(1 + i) = 1 + \pi^*_C$. Moreover, it is straightforward to verify that in steady state $\pi_C = \pi_D = \pi^h_X = \pi_w$.

Table 2 shows that the optimal (annualized) long-run inflation rate is positive and equal to 1.45 percent before trade integration. To understand this result, notice that firms' monopoly power in the downstream sector and positive unemployment benefits imply suboptimally low job-creation.[18] Since $\pi_C = \pi_w$, positive inflation raises the steady-state level of firm bargaining power η_t, favoring vacancy posting by firms. However, the Ramsey authority must trade the beneficial welfare effects of reducing these distortions against the costs of non-zero inflation implied by allocating resources to wage and price changes and by the departure from the Hosios condition (since $\pi_w > 0$ results in a steady-state value of η_t that is higher than ε). Compared to the zero inflation outcome, the Ramsey authority increases job creation.

The finding of an optimal positive long-run inflation is in contrast with the prescription of near zero inflation delivered by the vast majority of New Keynesian models in closed and open economy. While the costs of inflation outweigh the benefits of reducing other distortions in those models, this is no longer the case with a richer microfoundation of labor markets. In particular, the prescription of an optimal positive long-run inflation rate stems from the presence of wage stickiness and labor-market search and matching frictions. Wage stickiness, in fact, allows the Ramsey authority to optimally manipulate the firm's bargaining power to reduce inefficiencies in job creation. Absent sticky wages, a policy of zero inflation would be optimal also in our model, as shown in Appendix G.[19] In addition, when trade linkages are weak, the optimal long-run inflation rate is 2.44 percent absent price-setting frictions (see again Appendix G), confirming that welfare costs of price adjustment reduce the beneficial effects of positive wage inflation. Finally, while the model assumes quadratic wage and price adjustment costs, the results would be similar with

[18] In Appendix F, we derive the first-best allocation chosen by a benevolent social planner for the world economy. We then formally define the inefficiency wedges that characterize the market economy by comparing the equilibrium allocation in the decentralized economy to the one chosen by the social planner.

[19] In Appendix G, we also show that the optimal long-run inflation rate remains positive even in the presence of wage indexation.

staggered wage and price setting.[20]

Table 2 also presents the welfare gain from implementing the long-run optimal policy relative to the Fed's historical behavior. To avoid spurious welfare reversals, we assume identical initial conditions across different monetary policy regimes and include transition dynamics in the computation. We set all the state variables at their steady-state level under the historical policy at time $t = -1$, regardless of the monetary regime from $t = 0$ on.[21] We compare welfare under the continuation of historical policy from $t = 0$ on (which implies continuation of the historical steady state) to welfare under the optimal long-run policy from $t = 0$ on (which implies a transition between the initial implementation at $t = 0$ and the Ramsey steady state). We measure the long-run welfare gains of the Ramsey policy by computing the percentage increase Δ in consumption that would leave the household indifferent between policy regimes:

$$\sum_{t=0}^{\infty} \beta^t u\left(C_t^{Ramsey}, h_t^{Ramsey}, l_t^{Ramsey}\right) = \frac{u\left[\left(1 + \frac{\Delta}{100}\right) C^{Hist}, h^{Hist}, l^{Hist})\right]}{1 - \beta}.$$

Table 2 shows that the welfare gains from the Ramsey-optimal policy amount to 0.34 percent of annualized steady-state consumption.

An important implication of our results is that monetary policy affects the composition of trade along the extensive margin. Relative to a policy of strict price stability, the Ramsey-optimal policy results in a larger number of exported products—N_X is approximately 4 percent higher under the optimal policy. The reason is that employment gains induced by positive net inflation raise aggregate demand and income in both countries, stimulating producer entry into the domestic and export market.[22]

The dispersion of firm-level productivity, indexed by k_p, plays an important role for the optimal long-run inflation rate, π^R. In particular, π^R increases with lower productivity dispersion (i.e., an increase in k_p). For instance, when k_p increases by 25%, i.e., from 3.4 to 4.25, π^R increases from 1.45 to 1.98 percent. Intuitively, as the dispersion of firm-level productivity decreases, productivity levels are increasingly concentrated toward their lower bound $z_{\min}$. Accordingly, the average domestic productivity, $\tilde{z}_D$, falls, resulting in a higher optimal long-run inflation rate to increase job creation.

[20] Carlsson and Westermark (2016) show that staggered wage bargaining leads to the same prescription of a positive, optimal inflation rate in a search-and-matching model that features inefficiently low job creation. In Appendix G, we show that our results are robust to considering Calvo price-setting.

[21] The results are not sensitive to the choice of (identical) initial conditions for the state variables.

[22] The export productivity cutoff z_X is independent of steady-state inflation. The reason why steady-state inflation does not affect the productivity cutoff z_X is that a given change in π induces an equal change in the marginal revenue product of exporting an additional variety and its marginal cost, φf_X, thus leaving z_X unaffected.

However, the increase in the optimal long-run inflation rate is not monotone. For instance, π^R is 1.67 percent when $k_p = 4.8$, still higher relative to the benchmark calibration ($k_p = 3.4$) but lower relative to $k_p = 4.4$. Intuitively, when the reduction in average domestic productivity, $\tilde{z}_D$, is too large, the welfare cost of further raising inflation outweighs its benefit, i.e., the cost of further increasing inflation to raise job creation becomes too large.

Optimal Monetary Policy over the Business Cycle

Stochastic fluctuations in aggregate productivity modify the policy tradeoffs facing the Ramsey authorities by reintroducing the distortions eliminated by symmetry and absence of time variation in steady state. First, as in steady state, there is a tension between the beneficial effects of manipulating inflation and its costs. Second, there is a tradeoff between stabilizing consumer price inflation (which contributes to stabilizing domestic markups) and wage inflation (which stabilizes unemployment). Third, there is a tension between stabilizing domestic markups, $\mu_{D,t}$, and export markups, $\mu^h_{X,t}$. Finally, the Home and Foreign economies fluctuate around a steady state where unemployment is inefficiently high and the number of producers is inefficiently low. As a result, shocks trigger larger fluctuations in product and labor markets relative to the efficient allocation.

Figure 1 (dashed lines) shows impulse responses to a Home productivity increase under the Ramsey-optimal policy. Relative to the historical rule (i.e., a policy of near producer price stability, defined as zero deviation of average domestic producer inflation from trend), the Ramsey authority generates a much smaller increase in wage inflation and a larger departure from price stability (disinflation) in both economies.

Policy tradeoffs explain why a policy of price stability is suboptimal. First, as highlighted by Erceg, Henderson, and Levine (2000) in a baseline New Keynesian model and by Thomas (2008) in a New Keynesian model with search-and-matching frictions, a policy of price stability is suboptimal in the presence of both price and wage rigidity. A case against price stability arises because wage inflation is too volatile and markup stabilization correspondingly too strong under this policy. In addition, positive unemployment benefits generate real wage rigidities, i.e., a positive (negative) productivity shock is not fully absorbed by the rise (fall) of the real wage. Firms post too many vacancies and nominal wage adjustment costs are too large. As a result, price stability results in excessive employment volatility.[23]

[23] Notice, however, that a policy that completely stabilizes wage inflation is also suboptimal. In this case, there would be too much inflation and markup volatility.

Finally, domestic price stability is also suboptimal due to the asymmetric dynamics of domestic and export markups. Endogenous fluctuations in the export productivity cutoff $z_{X,t}$ open a wedge between domestic and export inflation in each country. Since the law of one price does not hold, the central bank cannot stabilize export markups by setting domestic producer price inflation equal to zero.[24]

As for the long-run optimal policy, we compare policy regimes by computing the welfare gains for the two countries from optimal policy. Specifically, we compute the percentage Δ of steady-state consumption that would make households indifferent between living in a world with uncertainty under monetary policy m, where $m = Ramsey$ or $Hist$, and living in a deterministic Ramsey world:

$$E_0 \sum_{t=0}^{\infty} \beta^t u(C_t^m, h_t^m l_t^m) = \frac{u\left[\left(1 + \frac{\Delta}{100}\right) C^{Ramsey}, h^{Ramsey} l^{Ramsey})\right]}{1-\beta}.$$

We compute welfare by resorting to a second-order approximation of the policy functions, since with a distorted steady state volatility affects both first and second moments of the variables that determine welfare. As shown in Table 2, by implementing the Ramsey-optimal policy the welfare cost of business cycle falls by approximately 35 percent: Optimal departures from price stability lower the cost of business cycles from 0.85 percent of steady-state consumption under the historical policy to 0.52 percent.

From a policy perspective, it is important to know whether the Ramsey-optimal policy can be implemented by mean of simple interest rate rules, and whether such optimal rules can be purely inward looking. To address this question, we consider a constrained Ramsey problem in which the Ramsey authority maximizes aggregate welfare in (7) by cooperatively choosing the optimal response coefficients in a general class of inward-looking interest rate rules.[25] We allow the interest rates in Home and Foreign to respond to four domestic variables: the previous-period interest rate, producer price inflation, wage inflation, and the output gap. For the Home economy, the interest rule has the following functional form (a similar expression holds for the Foreign country):

$$1 + i_{t+1} = (1 + i_t)^{\varrho_i} \left[(1 + i)(1 + \tilde{\pi}_{D,t})^{\varrho_{\pi_D}} (1 + \tilde{\pi}_{w,t})^{\varrho_{\pi_w}} \left(\tilde{Y}_{g,t}\right)^{\varrho_Y}\right]^{1-\varrho_i}. \tag{8}$$

The welfare maximizing rule implies: $\varrho_i = 0.81$, $\varrho_Y = 0$, $\varrho_{\pi_D} = 1.15$ and $\varrho_{\pi_w} = 2.08$. As

[24] This tradeoff is quantitatively less important when trade linkages are weak, since the dynamics of $\mu_{D,t}$ and $\mu_{X,t}^h$ are similar under the Ramsey-optimal policy.

[25] We only consider combinations of policy parameters that deliver a unique rational expectations equilibrium.

shown in Table 2, the welfare loss implied by the (constrained) optimal interest rule relative to the (unconstrained) Ramsey allocation is very small (approximately 3 percent, corresponding to 0.01 percent of steady state consumption). As a result, when trade linkages are weak, the Ramsey-optimal policy is well approximated by an inward-looking interest rate rule, i.e., each central bank can achieve the constraint, efficient allocation by appropriately responding to domestic targets.

6 Optimal Monetary Policy and Trade Integration

How does trade integration affect optimal monetary policy? Stronger trade linkages pose different challenges for the central banks of integrating countries. First, a permanent decline in trade costs may alter the optimal long-run inflation target. Second, lower trade costs may affect the way economies respond to aggregate shocks, with consequences for the optimal stabilization policy.

In our exercises, we interpret trade integration as a symmetric reduction of iceberg trade costs, τ and τ^*, capturing a decrease in several impediments to international trade such as tariffs and transportation costs.[26] We consider two scenarios. First, we re-calibrate τ_t and τ_t^* so that in the new steady state the trade-to-GDP ratio is 25 percent, the average value observed in the U.S. during the period $1980-2011$. Second, we consider a further reduction in trade costs that implies a trade-to-GDP ratio equal to 35 percent.

Optimal Long-Run Monetary Policy

The starting point of our analysis is a robust conclusion reached by empirical work using microlevel data: When the exposure to trade changes, the probability of exporting among non-exporters increase. Given the productivity advantage of exporters, this induces reallocations in favor of the more productive exporting plants, increasing average industry productivity (see Bernard, Jensen and Schott, 2006).

Our model, as Melitz (2003), is consistent with these stylized facts. Define a weighted productivity average $\tilde{z}$ that reflects the combined market shares of all Home firms and the output shrinkage linked to exporting: $\tilde{z} \equiv \left[\tilde{z}_D^{\theta-1} + (\tilde{z}_X/\tau)^{\theta-1} (N_X/N_D)\right]^{1/(\theta-1)}$. In response to trade integration, the relative more productive non-exporting plants begin to export and the market shares of the domestic plants shrink due to increased foreign competition. Even if the average productivity of the exporters ($\tilde{z}_X$) falls, the gain in market shares of existing and new exporting plants is strong

[26] Trade integration can also be interpreted as a permanent decrease in fixed export costs. Qualitatively, none of our results is affected by the specific nature of the "integration shock".

enough to guarantee that the average productivity $\tilde{z}$ increases.

This result has implications for the conduct of monetary policy. Table 2 shows that stronger trade linkages lower the steady-state optimal inflation rate, which becomes 1.1 percent when trade integration reaches its maximum. Intuitively, trade-induced productivity gains reduce the need to resort to positive inflation to correct market distortions. In particular, the increase in average productivity dampens the negative consequences of firms' monopoly power and distortionary unemployment benefits. To see this, let $\varkappa \equiv q/\iota$ be the labor-market tightness. Since $U = \lambda / (\lambda + \varkappa^{\varepsilon})$, the effect of trade integration on job creation is summarized by the response of $\varkappa$. As shown in Appendix G, the labor market tightness is an increasing function of the marginal revenue from a match, φ, i.e. $d\varkappa/d\varphi > 0$. Moreover, since $\varphi = (1/\mu_D) N_D^{1/(\theta-1)} \tilde{z}$, the marginal revenue of a match increases with the number of domestic goods available to consumers, N_D, and the average firm productivity, $\tilde{z}$. Trade openness leads to a decrease in N_D and to an increase in $\tilde{z}$. For any realistic parametrization of the model, the productivity effects dominate, implying that $\partial\varkappa/\partial\varphi > 0$. Thus, our model features a negative link between trade and unemployment, given that $\partial U/\partial\varkappa = -\partial\varkappa/\partial\varphi < 0$. As in Cacciatore (2014) and Felbermayr, Prat, and Schmerer (2011), the increase in $\tilde{z}$ makes workers on average more productive, increasing the average marginal revenue of a match and employment toward their efficient levels.[27] In turn, this explains why the optimal long-run inflation rate falls when trade costs are reduced.

Table 2 also shows the welfare gains from implementing the optimal policy response to trade integration (including transition dynamics) are positive but smaller that in the pre-integration scenario (welfare gains reduce from 0.45 percent of steady state consumption to 0.18 percent).

Optimal Monetary Policy over the Business Cycle

A second robust conclusion of empirical work is that, among industrialized economies, business cycles become more synchronized when trade linkages are stronger. In particular, by running cross-country regressions, the slope coefficient estimates in Frankel and Rose (1998) and Clark and van Wincoop (2001) imply that countries with 3.5 times larger trade intensity have a correlation that is, on average, 0.089 higher and 0.125 higher, respectively.[28] Table 3 shows the model correctly predicts business cycle synchronization in response to trade integration. In particular, under the

[27] Dutt, Mitra and Ranjan (2009) and Felbermayra, Prat and Schmerer (2011) document empirically the negative long-run relationship between trade openness unemployment. See Pissarides and Vallanti (2007) for evidence that higher productivity lowers unemployment in the long run.

[28] See also Baxter and Kouparitsas (2005), Calderon, Chong and Stein (2007), and di Giovanni and Levchenko (2010).

historical monetary policy making, the model predicts that cross-country GDP correlation increase from 0.27 to 0.43 when trade volumes are 3.5 larger.[29]

The ability of the model to account for the business cycle synchronization observed in the data has often eluded standard international business cycle models, the so-called trade and comovement puzzle identified by Kose and Yi (2001).[30] The success of our model on the trade and comovement front relates to the findings in Cacciatore (2014). He shows that endogenous product dynamics and labor market frictions introduce a strong internal propagation mechanism in the model, which translates in long-lasting effects of domestic shocks abroad with strong trade linkages. Second, as previously discussed, firm heterogeneity mitigates the terms-of-trade effects of aggregate shocks, reducing the incentives to shift resources across countries over the cycle.

We now discuss the consequences of trade integration for the conduct of monetary policy over the business cycle. Figure 2 shows the optimal monetary policy does not change after trade integration. The Ramsey authority continues to strike a balance between stabilizing price and wage inflation in both countries. Moreover, the optimized inward-looking interest rate rules derived in the previous section can still replicate closely the constrained efficient allocation. Even when the trade-to-GDP ratio is 35 percent, there are virtually no differences between the welfare costs of business cycle under the Ramsey-optimal policy and the optimized rules (see Table 2).

Our results echo the finding in Benigno and Benigno (2003), who show that when aggregate shocks are perfectly correlated across countries, only domestic distortions determine policy trade-offs.[31] In our model, increased trade integration results (endogenously) in stronger business cycle comovement. Thus, inward-looking interest rate rules can still replicate the constrained efficient allocation. Put differently, when stronger trade linkages result into plausible business cycle synchronization, there is no shift in the focus of monetary stabilization to redressing domestic as well as external distortions, i.e., trade integration does not require targeting rules involving misalignments in the terms of trade or cross-country demand imbalances.

A question remains open: what are the consequences of trade integration when monetary policy

[29] This figure is not directly comparable with the empirical estimates, since the latter refer to an increase in the average bilateral trade intensity. For this reason, we have also considered an alternative calibration of trade costs, setting the initial value of τ and τ^* to generate a 0.5 percent bilateral trade intensity, the average value for the U.S. in the period $1954 - 1980$. Then, we reduced trade costs to increase the bilateral trade intensity by a factor of 3.5. The predicted increase in GDP comovement is 0.085, in line with empirical estimates.

[30] The Backus, Kehoe and Kydland (1992) model augmented with trade costs yields the counterfactual prediction of a smaller cross-country GDP correlation following reductions in trade costs. Production reallocation towards more productive locations more than offsets demand complementarities induced by lower trade costs.

[31] When productivity shocks are perfectly correlated across countries, the optimal cooperative policy in Benigno and Benigno (2003) dictates a flexible exchange rate and domestic price stability. Notice their model features frictionless labor markets and flexible wages.

is not optimally designed? Table 2 shows that historical (Fed) policy behavior results in more sizable welfare costs relative to the pre-integration scenario: The welfare gains from implementing the Ramsey-optimal policy relative to historical policy making increase from 36 percent (with high trade costs) up to approximately 50 percent. To understand this result, recall that historical policy results in suboptimal unemployment dynamics in each country, inducing inefficient fluctuations in terms of trade and cross-country demand. For example, Figure 2 shows that following an increase in Home productivity, terms of trade depreciation is too weak relative to the constrained efficient allocation since the Home economy expands production beyond its efficient level. When trade linkages are strong, sub-optimal terms-of-trade fluctuations combine with incomplete risk sharing across countries, resulting in inefficient international spillovers and larger welfare costs of historical policy.

To summarize, our analysis has two main implications for the conduct of monetary policy following trade integration. First, provided that central banks appropriately use inflation to smooth domestic unemployment fluctuations, inward-looking interest rate rules (and a flexible exchange rate) remain optimal. However, sub-optimal inward-looking policies (such as a policy of price stability), become more costly when trade linkages are stronger due to the negative consequences of (inefficient) international spillovers.

7 Extensions

Thus far, we assumed complete exchange rate pass-through and abstracted from strategic considerations in monetary policy setting. In the data, however, exchange rate pass-through is far from complete and monetary policy can involve strategic currency devaluations. As a result, the benchmark model could underestimate the importance of external distortions for the optimal conduct of monetary policy. We turn to these issues next, investigating the robustness of our findings to the presence of local currency pricing (LCP) and non-cooperative monetary policy setting.

Local Currency Pricing Under local currency pricing (LCP), firms set prices in domestic currency for the domestic market and in foreign currency for the market of destination. As a result, nominal exchange rate movements do not have expenditure switching effects: Nominal depreciation does not make goods produced in the country cheaper worldwide, thus re-allocating demand in favor of them. We derive the optimal export prices under LCP in Appendix B.[32]

How does LCP affect the policy tradeoffs faced by the Ramsey authority? A well-known theoretical result in the literature is that incomplete pass-through makes it is impossible to simultaneously stabilize domestic and export markups since the law of one price does not hold. The optimal-policy prescription is that policymakers should pay attention to international relative price misalignments, as the exchange rate cannot be expected to correct them. In our model, however, the law of one price does not hold regardless of the currency denomination of exports. As a result, LCP does not introduce new policy tradeoffs for the Ramsey authority, but it modifies their nature with respect to PCP.

As shown by Figure 3, when trade linkages are weak, the optimal policy continues to stabilize unemployment fluctuations, generating higher domestic markups volatility in the relatively more productive economy. Table 2 shows the welfare costs of historical policy under PCP and LCP remain close, and the optimized inward-looking interest rate rule obtained under PCP continue to approximate well the Ramsey allocation. These results are not surprising since differences in the international transmission of aggregate shocks are expected to have second-order welfare implications when trade linkages are weak.

The key finding is that the cooperative, optimized interest rate rules that we derived under PCP and weak trade linkages continue to be optimal after trade integration even with LCP. Intuitively, provided that each central bank responds appropriately to movements in price and wage inflation, business cycle synchronization offsets international distortions: When shocks are more global, asymmetries in the dynamics of domestic and export markups are reduced and the need to correct for real exchange rate misalignment and cross-country misallocation in consumption correspondingly mitigated.

Table 2 also shows that sub-optimal domestic stabilization continues to be costly in terms of welfare. Moreover, the welfare loss relative to the Ramsey optimal policy are larger under LCP compared to what observed in the presence of PCP. As shown by Figure 4, historical policy implies that Home terms of trade do not depreciate enough in response to an increase in Home productivity due the lack of unemployment stabilization. Since the optimal terms-of-trade depreciation engineered by the Ramsey authority is larger under LCP relative to PCP, historical policy becomes more costly.

[32] For simplicity we assume that all the producers set export prices in Foreign currency. The model could be easily extended to allow for an exogenous partition of firms operating under PCP and LCP.

Optimal Non-Cooperative Monetary Policy We now investigate whether strategic considerations affect the conduct of monetary policy in the presence of trade integration. As common practice in the literature, we consider two self-oriented central banks that set monetary policy to maximize the welfare of domestic consumers.

The strategic game follows Benigno and Benigno (2006). We specify each policymaker's strategy in terms of each country's consumer price inflation rate, $\pi_{C,t}$, taking as given the sequence of the other country's consumer price inflation rates (a two-country, open-loop Nash equilibrium). Thus, the Home central bank maximizes $E_0 \sum_{t=0}^{\infty} \beta^t \left[u(C_t) - l_t v(h_t)\right]$, taking as given $\left\{\pi^*_{C,t}\right\}_{t=0}^{\infty}$. The central in Bank in Foreign solves an analogous maximization problem, taking as given $\{\pi_{C,t}\}_{t=0}^{\infty}$.

In a Nash equilibrium, domestic policymakers have an incentive to manipulate their country's terms of trade, resulting in inefficient exchange rate volatility relative to the constrained efficient benchmark of policy cooperation. Table 2 shows that when trade linkages are weak, the welfare loss associated to the non-cooperative outcome is very modest (almost 0 percent, regardless of the assumptions about the currency denomination of export). Intuitively, weak trade linkages imply that each policymaker has no incentives to manipulate terms of trade.

Stronger trade linkages do not significantly change this conclusion. Table 2 shows that the welfare costs of non-cooperative monetary policy relative to the Ramsey-optimal allocation reach at most 0.2 percent.[33] Once again, this result is explained by the increase in comovement induced by trade integration (see Table 3): business cycle synchronization reduces the incentives to manipulate terms of trade since shocks become more global.[34]

8 Conclusions

We re-examined classic questions on trade integration and international monetary policy using a dynamic, stochastic, general equilibrium model with micro-level trade dynamics and labor market frictions. We have shown that trade-induced productivity gains reduce the need of positive inflation to correct long-run distortions. Over the business cycle, optimized inward-looking policy rules can still approximate the optimal cooperative outcome, as stronger trade linkages result in increased

[33] We have also considered the case in which the optimal non-cooperative problem is described in terms of particular interest rate rules. In this case, each central bank maximizes the domestic welfare by choosing the coefficients of the interest rate rule in equation (8). The best response coefficients for each policymaker do not differ from the cooperative equilibrium regardless of the level of trade integration (results are available upon request).

[34] Absent search and matching frictions and endogenous producer entry, with strong trade linkages the welfare cost of business cycles under the Nash-optimal policy can be 20 percent higher relative to the optimal-cooperative policy (see Appendix I and the results in Coenen, Lombardo, Smets, and Straub, 2007).

business cycle synchronization. By contrast, sub-optimal, inward-looking stabilization—for instance too narrow a focus on price stability—results in larger welfare costs.

Much remains to be done in this area of research. We modeled trade integration as an exogenous reduction in tariffs (iceberg trade costs), but trade integration may also take the form of lower fixed costs of trade. Moreover, we did not analyze optimal trade policy nor its potentially strategic interdependence with monetary policymaking. Finally, our analysis abstracts from zero-lower-bound considerations and the role of financial frictions, additional dimensions that may affect how trade linkages shape monetary policy tradeoffs. We view these as important, promising areas where to take this research next.

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TABLE 1: CALIBRATION

Risk Aversion	$\gamma_C = 1$	Pareto Shape	$k_p = 3.4$
Frisch elasticity	$1/\gamma_h = 0.25$	Pareto Support	$z_{\min} = 1$
Discount Factor	$\beta = 0.99$	Sunk Entry Cost	$f_E = 0.98$
Matching Function	$\varepsilon = 0.6$	Fixed Export Costs	$f_X = 0.0015$
Firm Bargaining Power	$\eta = 0.6$	Iceberg Trade Costs	$\tau - 1 = 1.47$
Unemployment benefit	$b = 1.2$	Rotemberg Wage Adj. Cost	$\vartheta = 290$
Exogenous separation	$\lambda = 0.10$	Rotemberg Price Adj. Cost	$\nu = 80$
Vacancy Cost	$\kappa = 0.74$	Taylor - Interest Rate Smoothing	$\varrho_i = 0.71$
Matching Efficiency	$\chi = 0.72$	Taylor - Inflation Parameter	$\varrho_\pi = 1.62$
Elasticity of Substitution	$\theta = 3.8$	Taylor - Output Gap Parameter	$\varrho_Y = 0.34$
Plant Exit	$\delta = 0.021$	Bond Adjustment Cost	$\psi = 0.0025$

TABLE 2: WELFARE EFFECTS OF TRADE INTEGRATION

Steady State	$\frac{Trade}{GDP} = 0.1$	$\frac{Trade}{GDP} = 0.25$	$\frac{Trade}{GDP} = 0.35$
Ramsey-Optimal Long-Run Inflation	1.45%	1.22%	1.10%
Welfare Gain from Ramsey Cooperation	0.45%	0.25%	0.18%
Welfare Cost of Business Cycles, Loss Relative to Ramsey-Optimal Cooperative Policy (PCP)			
Historical Rule	36.8%	43.72%	49.1%
Optimal-Cooperative Rule	3.14%	3.82%	3.96%
Nash-Optimal Policy	0.00%	0.04%	0.13%
Welfare Cost of Business Cycles, Loss Relative to Ramsey-Optimal Cooperative Policy (LCP)			
Historical Rule	37.11%	45.48%	52.48%
Optimal-Cooperative Rule	4.66%	5.10%	5.87%
Nash-Optimal Policy	0.00%	0.07%	0.17%

Note: Welfare loss relative to optimal policy $\equiv$ percentage change in welfare costs of business cycle

TABLE 3: TRADE INTEGRATION AND GDP COMOVEMENT

	$\Delta corr(Y_{R,t}, Y^*_{R,t})$—Producer Currency Price		
	$\frac{Trade}{GDP} = 10\%$	$\frac{Trade}{GDP} = 25\%$	$\frac{Trade}{GDP} = 35\%$
Historical Rule	0.27	0.36	0.43
Ramsey-Optimal Policy	0.26	0.36	0.42
Nash-Optimal Policy	0.26	0.36	0.42
	$corr(Y_{R,t}, Y^*_{R,t})$—Local Currency Price		
	$\frac{Trade}{GDP} = 10\%$	$\frac{Trade}{GDP} = 25\%$	$\frac{Trade}{GDP} = 35\%$
Historical Rule	0.27	0.36	0.43
Ramsey-Optimal Policy	0.27	0.35	0.43
Nash-Optimal Policy	0.27	0.35	0.43

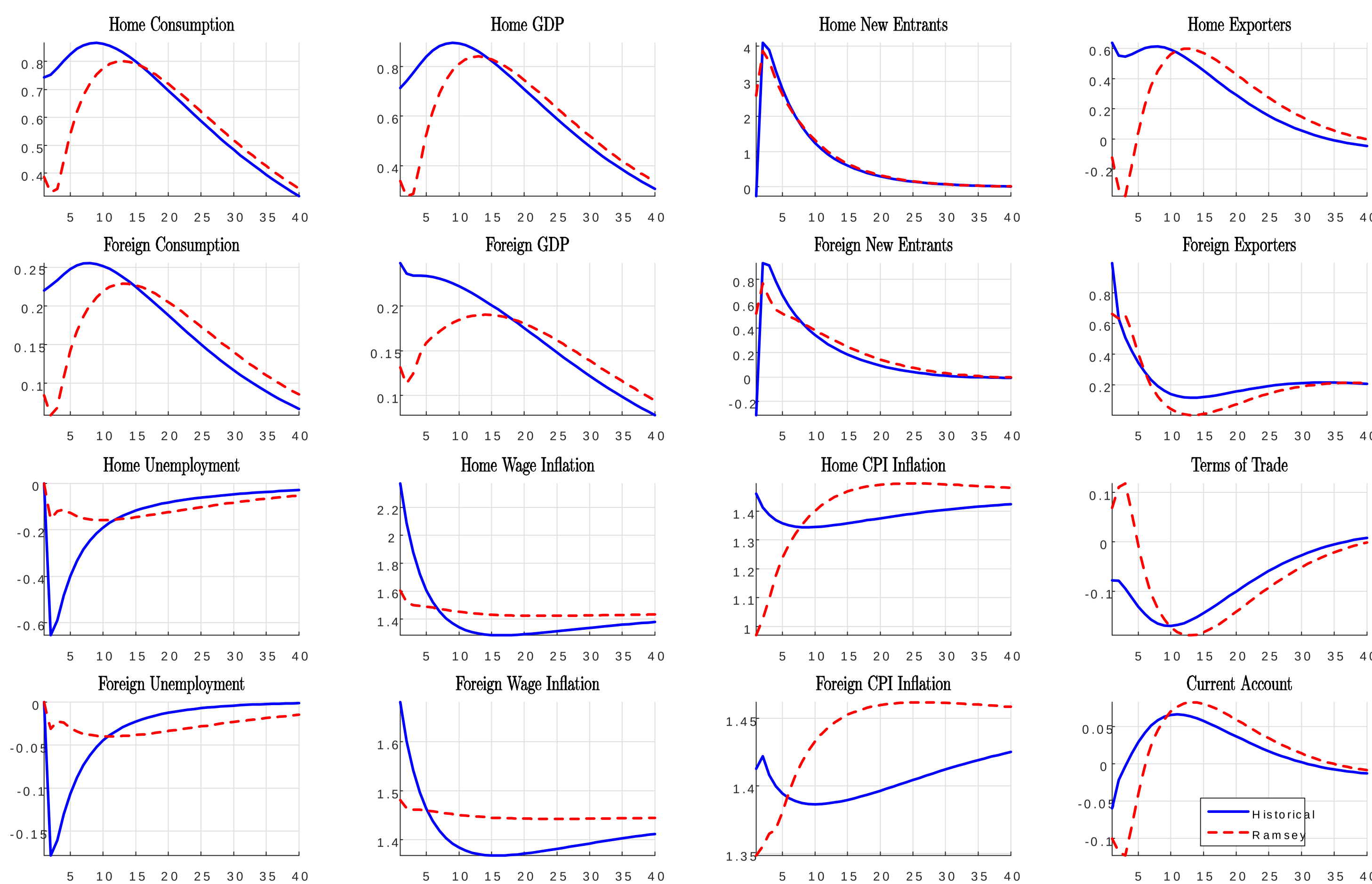

Figure 1: Figure 1: Home poductivity shock, weak trade linkages and producer currency pricing. Variables are in percentage deviations from the steady state. Unemployment and inflation are in deviations from the steady state.

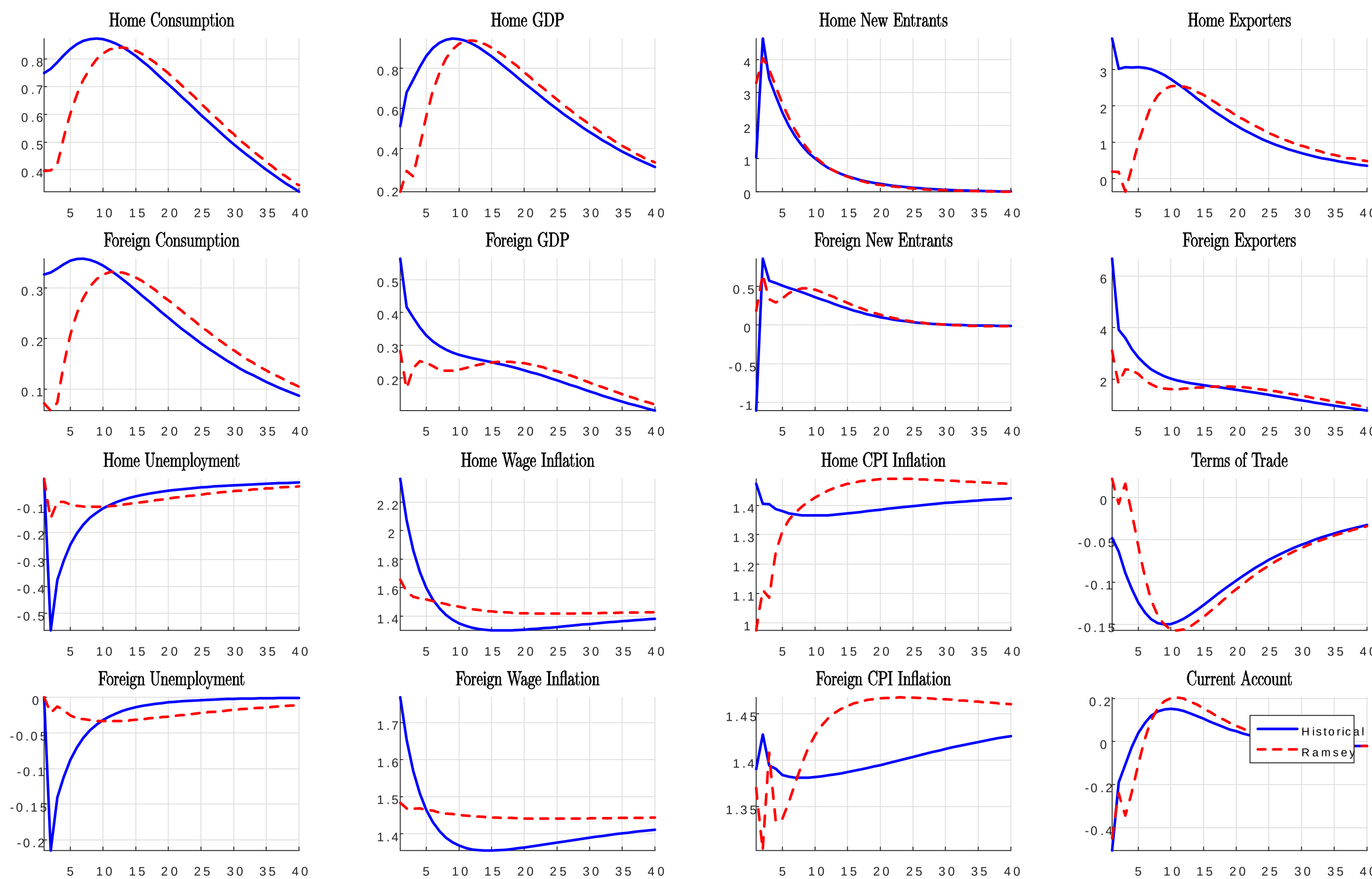

Figure 2: Figure 2: Home productivity shock, trade integration and producer currency pricing. Variables are in percentage deviations from the steady state. Unemployment and inflation are in deviations from the steady state.

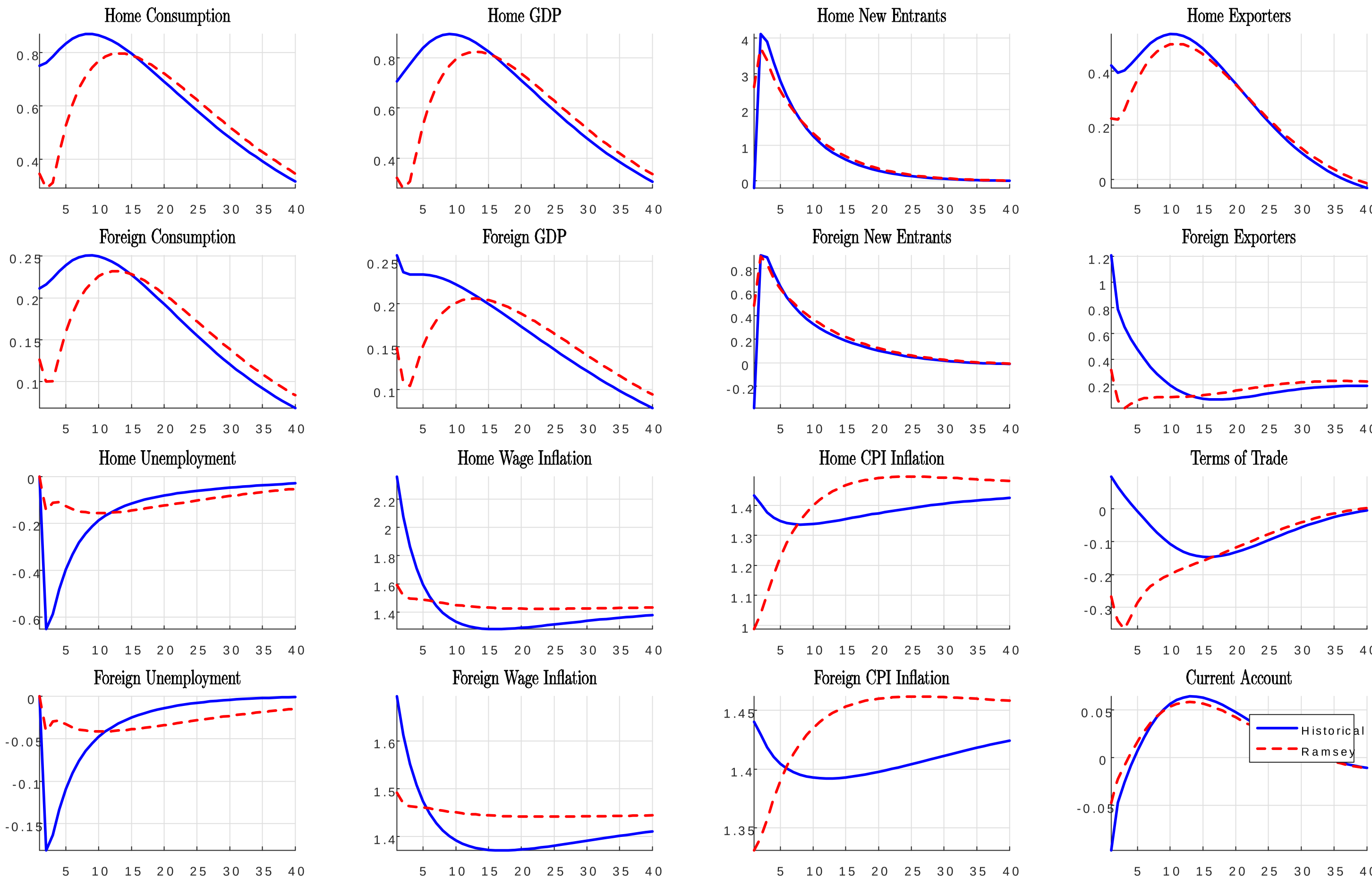

Figure 3: Figure 3: Home productivity Sshock, weak trade linkages and local currency pricing. Variables are in percentage deviations from the steady state. Unemployment and inflation are in deviations from the steady state.

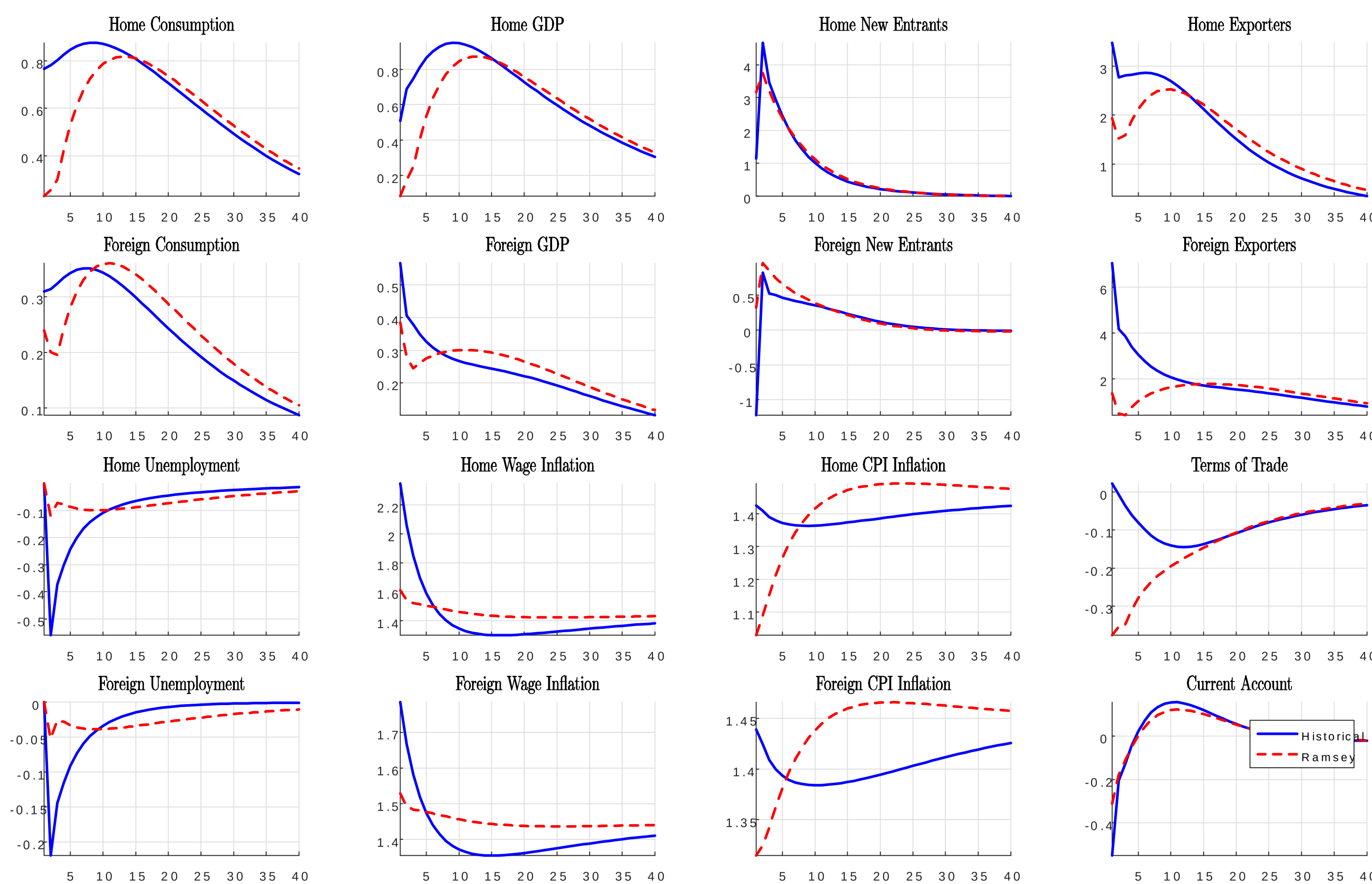

Figure 4: Figure 4: Home productivity shock, trade integration and local currency pricing. Variables are in percentage deviations from the steady state. Unemployment and inflation are in deviations from the steady state.

Online Technical Appendix to "Trade, Unemployment, And Monetary Policy

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A Wage Determination

The nominal wage is the solution of an individual Nash bargaining process, and the wage payment divides the match surplus between workers and firms. Let J_t be the real value of an existing productive match:

$$J_t = \varphi_t Z_t h_t - \frac{w_t^n}{P_t} h_t - \frac{\vartheta}{2}\pi_{w,t}^2 + E_t \beta_{t,t+1}(1-\lambda)J_{t+1}. \tag{1}$$

Intuitively, J_t is the per-period marginal value product of the match, $\varphi_t Z_t h_t$, net of the wage bill and costs incurred to adjust wages, plus the expected discounted continuation value of the match in the future.

Next, denote with W_t the worker's asset value of being matched, and with $U_{u,t}$ the value of being unemployed. The value of being employed at time t is given by the real wage bill the worker receives plus the expected future value of being matched to the firm. With probability $1-\lambda$ the match will survive, while with probability λ the worker will be unemployed. As a result:

$$W_t = \frac{w_t}{P_t} h_t + E_t \left\{ \beta_{t,t+1} \left[(1-\lambda) W_{t+1} + \lambda U_{u,t+1} \right] \right\}. \tag{2}$$

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The value of unemployment is given by:

$$U_{u,t} = \frac{v(h_t)}{u_{C,t}} + b + E_t \left\{ \beta_{t,t+1} [\iota_t W_{t+1} + (1 - \iota_t) U_{u,t+1}] \right\}. \tag{3}$$

In this expression, $v(h_t)/u_{C,t}$ is the utility gain from leisure in terms of consumption, b is an unemployment benefit from the government (financed with lump sum taxes), and ι_t is the probability of becoming employed at time t, equal to the ratio between the total number of matches and the total number of workers searching for jobs at time t: $\iota_t \equiv M_t/U_t$.

Equations (2) and (3) imply that the worker's surplus $H_t \equiv W_t - U_{u,t}$ is determined by:

$$H_t = \frac{w_t}{P_t} h_t - \left(\frac{v(h_t)}{u_{C,t}} + b \right) + (1 - \lambda - \iota_t) E_t \left(\beta_{t,t+1} H_{t+1} \right). \tag{4}$$

Nash bargaining maximizes the joint surplus $J_t^{\eta} H_t^{1-\eta}$ with respect to w_t, where $\eta \in (0, 1)$ is the firm's bargaining power. The first-order condition implies:

$$\eta H_t \frac{\partial J_t}{\partial w_t} + (1 - \eta) J_t \frac{\partial H_t}{\partial w_t} = 0, \tag{5}$$

where:

$$\frac{\partial J_t}{\partial w_t} = -\frac{h_t}{P_t} - \vartheta \frac{\pi_{w,t}}{w_{t-1}} + (1 - \lambda) \vartheta E_t \left[\beta_{t,t+1} (1 + \pi_{w,t+1}) \frac{\pi_{w,t+1}}{w_t} \right], \tag{6}$$

and:

$$\frac{\partial H_t}{\partial w_t} = \frac{h_t}{P_t}. \tag{7}$$

The sharing rule can then be rewritten as:

$$\eta_t H_t = (1 - \eta_t) J_t, \tag{8}$$

where:

$$\eta_t = \frac{\eta}{\eta - (1 - \eta) \left(\frac{\partial H_t}{\partial w_t} / \frac{\partial J_t}{\partial w_t} \right)}. \tag{9}$$

Equation (8) shows that bargaining shares are time-varying due to the presence of wage adjustment costs. Absent wage adjustment costs, we would have $\partial J_t / \partial w_t = -\partial H_t / \partial w_t$ and a time-invariant bargaining share $\eta_t = \eta$. The bargained wage satisfies:

$$\begin{aligned}\frac{w_t}{P_t} h_t &= \eta_t \left(\frac{v(h_t)}{u_{C,t}} + b\right) + (1-\eta_t)\left(\varphi_t Z_t h_t - \frac{\vartheta}{2}\pi^2_{w,t}\right) \\ &\quad + E_t\left\{\beta_{t,t+1} J_{t+1}\left[(1-\lambda)(1-\eta_t) - (1-\lambda-\iota_t)(1-\eta_{t+1})\frac{\eta_t}{\eta_{t+1}}\right]\right\}, \qquad (10)\end{aligned}$$

Finally, notice that equation (10) implies that the value of a match to a producer can be rewritten as:

$$J_t = \eta_t\left[\varphi_t Z_t h_t - \frac{\vartheta}{2}\pi^2_{w,t} - \left(\frac{v(h_t)}{u_{C,t}} + b\right)\right] + E_t\left\{\beta_{t,t+1} J_{t+1}\left[(1-\lambda)\eta_t + (1-\lambda-\iota_t)(1-\eta_{t+1})\frac{\eta_t}{\eta_{t+1}}\right]\right\}.$$

The second term in the right-hand side of this equation reduces to $[1-\lambda-(1-\eta)\,\iota_t]\, E_t\left(\beta_{t,t+1}J_{t+1}\right)$ when wages are flexible. The firm's equilibrium surplus is the share η of the marginal revenue product generated by the worker, net of wage adjustment costs and the worker's outside option, plus the expected discounted future surplus, adjusted for the probability of continuation, $1-\lambda$, and the portion appropriated by the worker, $(1-\eta)\,\iota_t$. Sticky wages again introduce an effect of expected changes in the endogenous bargaining shares.

B Pricing Decisions

Here we derive the optimal price for the domestic and export bundles.

B.1 Producer Currency Pricing

Each final producer sets $P_{D,t}$ and the domestic currency price of the export bundle, $P^h_{X,t}$, letting the price in the foreign market be determined by $P_{X,t} = P^h_{X,t}/S_t$, where S_t is the nominal exchange rate. The present discounted value of the stream of profits Π_t is:

$$\Pi_t = E_t \sum_{s=t}^{\infty} \beta_{t,s} \left\{ \begin{array}{c} \left[\left(\frac{P_{D,s}}{P_s}\right)\left(1 - \frac{\nu}{2}\left(\frac{P_{D,s}}{P_{D,s-1}} - 1\right)^2\right) - \varphi_{D,s}\right] Y_{D,s} \\ + \left[\left(\frac{P^h_{X,s}}{P_s}\right)\left(1 - \frac{\nu}{2}\left(\frac{P^h_{X,s}}{P^h_{X,s-1}} - 1\right)^2\right) - \varphi_{X,s}\tau_s\right] Y_{X,s} - N_{E,t} f_{E,s} - N_{X,s} f_{X,t} \end{array} \right\},$$

where

$$Y_{D,t} = \left(\frac{P_{D,t}}{P_t}\right)^{-\phi} Y^C_t, \qquad Y_{X,t} = \left(\frac{P^h_{X,t}}{Q_t P_t}\right)^{-\phi} Y^{C^*}_t.$$

The first order condition for $P_{D,t}$ yields:

$$\rho_{D,t} \equiv \frac{P_{D,t}}{P_t} = \mu_{D,t}\varphi_{D,t}, \tag{11}$$

where $\mu_{D,t}$ is the time-varying markup:

$$\mu_{D,t} \equiv \frac{\phi}{(\phi-1)\left(1-\frac{\nu}{2}\pi_{D,t}^2\right)+\nu\left\{(1+\pi_{D,t})\,\pi_{D,t}-E_t\left[\beta_{t,t+1}\frac{\left(1+\pi_{D,t+1}\right)^2}{1+\pi_{t+1}^C}\pi_{D,t+1}\frac{Y_{D,t+1}}{Y_{D,t}}\right]\right\}} \tag{12}$$

and $\pi_{D,t} \equiv P_{D,t}/P_{D,t-1}-1$. The first order condition for $P_{X,t}^h$ yields:

$$\rho_{X,t}^h \equiv \frac{P_{X,t}^h}{P_t} = \tau_t\mu_{X,t}^h\varphi_{X,t}, \tag{13}$$

where the time-varying export markup, $\mu_{X,t}^h$, is given by:

$$\mu_{X,t}^h \equiv \frac{\phi}{(\phi-1)\left(1-\frac{\nu}{2}\left(\pi_{X,t}^h\right)^2\right)+\nu\left\{\left(1+\pi_{X,t}^h\right)\pi_{X,t}^h-E_t\left[\beta_{t,t+1}\frac{\left(1+\pi_{X,t+1}^h\right)^2}{1+\pi_{t+1}^C}\pi_{X,t+1}^h\frac{Y_{X,t+1}}{Y_{X,t}}\right]\right\}} \tag{14}$$

and $\pi_{X,t}^h \equiv P_{X,t}^h/P_{X,t-1}^h-1$. Since $P_t = S_tP_t^*/Q_t$ and $P_{X,t}^h = P_{X,t}S_t$, equation (13) can be rearranged to obtain:

$$\rho_{X,t} \equiv \frac{P_{X,t}}{P_t^*} = \mu_{X,t}^h\frac{\tau_t}{Q_t}\varphi_{X,t}.$$

B.2 Local Currency Pricing

Under LCP the costs of adjusting the export price, expressed in units of Home currency, is given by $\Gamma_{x,t} \equiv \nu\pi_{x,t}^2S_tP_{x,t}Y_{x,t}/2$, where $\pi_{X,t} = (P_{X,t}/P_{X,t-1})-1$. Equation (11) still determines the domestic price $P_{D,t}$. However, when the export price is set in Foreign currency, each producer chooses $P_{X,t}$ to maximize:

$$\Pi_t = E_t\sum_{s=t}^{\infty}\beta_{t,s}\left\{\begin{array}{c}\left[\left(\frac{P_{D,s}}{P_s}\right)\left(1-\frac{\nu}{2}\left(\frac{P_{D,s}}{P_{D,s-1}}-1\right)^2\right)-\varphi_{D,s}\right]Y_{D,s}\\ +\left[\left(\frac{S_tP_{X,s}}{P_s}\right)\left(1-\frac{\nu}{2}\left(\frac{P_{X,s}}{P_{X,s-1}}-1\right)^2\right)-\varphi_{X,s}\tau_s\right]Y_{X,s}-N_{E,t}f_{E,s}-N_{X,s}f_{X,t}\end{array}\right\},$$

where

$$Y_{D,t} = \left(\frac{P_{D,t}}{P_t}\right)^{-\phi}Y_t^C, \qquad Y_{X,t} = \left(\frac{P_{X,t}}{P_t^*}\right)^{-\phi}Y_t^{C^*}.$$

The first order condition with respect to $P_{X,t}$ implies:

$$\frac{P_{X,t}}{P_t^*} = \mu_{X,t}\frac{\tau_t}{Q_t}\varphi_{X,t},$$

where the export markup, $\mu_{X,t}$ is given by:

$$\mu_{X,t} \equiv \frac{\phi}{(\phi-1)\left(1-\frac{\nu}{2}\pi_{X,t}^2\right)+\nu\left\{\pi_{X,t}\left(1+\pi_{X,t}\right)-E_t\left[\beta_{t,t+1}\frac{Q_{t+1}}{Q_t}\pi_{X,t+1}\frac{\left(1+\pi_{X,t+1}\right)^2}{\left(1+\pi_{t+1}^{C*}\right)}\frac{Y_{X,t+1}}{Y_{X,t}}\right]\right\}}.$$

C Equilibrium

The aggregate stock of employed labor in the Home economy is determined by $l_t = (1-\lambda)l_{t-1} + q_{t-1}V_{t-1}$. Wage inflation and consumer price inflation are tied by $1+\pi_{w,t} = \left(w_t^r/w_{t-1}^r\right)(1+\pi_{C,t})$, where $w_t^r \equiv w_t/P_t$ denotes the real wage. Moreover, domestic and export price inflation are tied to consumer price inflation by:

$$\frac{(1+\pi_{D,t})}{(1+\pi_{C,t})} = \frac{\tilde{\rho}_{D,t}}{\tilde{\rho}_{D,t-1}}\left(\frac{N_{D,t}}{N_{D,t-1}}\right)^{\frac{1}{1-\theta}}, \qquad \frac{\left(1+\pi_{X,t}^h\right)}{(1+\pi_{C,t})} = \frac{Q_t\tilde{\rho}_{X,t}}{Q_{t-1}\tilde{\rho}_{X,t-1}}\left(\frac{N_{X,t}}{N_{X,t-1}}\right)^{\frac{1}{1-\theta}}.$$

The equilibrium price index implies:

$$1 = \tilde{\rho}_{D,t}^{1-\theta}N_{D,t}^{\frac{1-\phi}{1-\theta}} + \tilde{\rho}_{X,t}^{*1-\theta}N_{X,t}^{*\frac{1-\phi}{1-\theta}}.$$

In equilibrium, lump-sum transfers are given by

$$T_t^g = -P_t b(1-l_t), \tag{15}$$

$$T_t^A = P_t\frac{\psi}{2}\left(\frac{A_{t+1}}{P_t}\right)^2 + S_t P_t\frac{\psi}{2}\left(\frac{A_{*,t+1}}{P_t^*}\right)^2, \tag{16}$$

$$T_t^i = P_t\left(\varphi_t Z_t l_t - \frac{w_t}{P_t}l_t - \kappa V_t - \frac{\vartheta}{2}\pi_{w,t}^2 l_t\right), \tag{17}$$

$$T_t^f = \left(\frac{\mu_{D,t}-1}{\mu_{D,t}} - \frac{\nu}{2}\left(\pi_{D,t}\right)^2\right)\widetilde{\rho}_{D,t}N_{D,t}\widetilde{y}_{D,t} + Q_t\left(\frac{\mu_{X,t}^h-1}{\mu_{X,t}^h} - \frac{\nu}{2}\left(\pi_{X,t}\right)^2\right)\widetilde{\rho}_{X,t}N_{X,t}\widetilde{y}_{X,t} - \varphi_t\left(N_{X,t}f_{X,t} + N_{E,t}f_{E,t}\right). \tag{18}$$

Aggregate demand must be equal to the sum of market consumption, the costs of posting vacancies, and the costs of adjusting prices and wages:

$$Y_t^C = C_t - h_p(1-l_t) + \kappa V_t + \frac{\vartheta}{2}\pi_{w,t}^2 l_t + \Gamma_{D,t} + \Gamma_{X,t}^h.$$

Labor market clearing requires:

$$l_t h_t = \frac{N_{D,t}\tilde{y}_{D,t}}{Z_t \tilde{z}_D} + \tau_t \frac{N_{X,t}\tilde{y}_{X,t}}{Z_t \tilde{z}_{X,t}} + \frac{N_{E,t} f_{E,t}}{Z_t} + \frac{N_{X,t} f_{X,t}}{Z_t}.$$

Finally, we derive the law of motion for net foreign assets. Recall the representative household's budget constraint:

$$\begin{aligned} A_{t+1} + S_t A_{*,t+1} + \frac{\psi}{2} P_t \left(\frac{A_{t+1}}{P_t}\right)^2 + \frac{\psi}{2} S_t P_t^* \left(\frac{A_{*,t+1}}{P_t^*}\right)^2 + P_t C_t = \\ = (1+i_t)A_t + (1+i_t^*)S_t A_{*,t} + w_t l_t + P_t b(1-l_t) + T_t^g + T_t^A + T_t^i + T_t^f. \end{aligned} \tag{19}$$

Using equations (15)-(18), the resource constraint can be written as:

$$\begin{aligned} A_{t+1} + S_t A_{*,t+1} + P_t C_t = (1+i_t)A_t + (1+i_t^*)S_t A_{*,t} + P_t \varphi_t Z_t l_t h_t - P_t \kappa V_t - P_t \frac{\vartheta}{2}\pi_{w,t}^2 l_t + \\ + \left(\frac{\mu_{D,t}-1}{\mu_{D,t}} - \frac{\nu}{2}(\pi_{D,t})^2\right)\tilde{\rho}_{D,t} N_{D,t}\tilde{y}_{D,t} + Q_t \left(\frac{\mu_{X,t}^h - 1}{\mu_{X,t}^h} - \frac{\nu}{2}(\pi_{X,t})^2\right)\tilde{\rho}_{X,t} N_{X,t}\tilde{y}_{X,t} - \varphi_t \left(N_{X,t} f_{X,t} + N_{E,t} f_{E,t}\right). \end{aligned} \tag{20}$$

Recall the expression for Home's aggregate demand of the consumption basket:

$$Y_t^C = C_t + \kappa V_t + \frac{\vartheta}{2}\pi_{w,t}^2 l_t + \frac{\nu}{2}\pi_{D,t}^2 \tilde{\rho}_{D,t} N_{D,t}\tilde{y}_{D,t} + \frac{\nu}{2}\pi_{X,t}^2 \tilde{\rho}_{X,t} N_{X,t}\tilde{y}_{X,t}.$$

After rearranging, equation (20) can be rewritten in real terms as:

$$\begin{aligned} a_{t+1} + Q_t a_{*,t+1} = \frac{1+i_t}{1+\pi_{C,t}} a_t + Q_t \frac{1+i_t^*}{1+\pi_{C,t}^*} a_{*,t} + N_{D,t}\tilde{\rho}_{X,t}\tilde{y}_{X,t} + Q_t N_{X,t}\tilde{\rho}_{X,t}\tilde{y}_{X,t} - Y_t^C + \\ + \varphi_t Z_t l_t h_t + \frac{\tilde{\rho}_{D,t}}{\mu_{D,t}} N_{D,t}\tilde{y}_{D,t} + \frac{Q_t \tilde{\rho}_{X,t}}{\mu_{X,t}^h} N_{X,t}\tilde{y}_{D,t} - \varphi_t N_{X,t} f_{X,t} - \varphi_t N_{E,t} f_{E,t}. \end{aligned} \tag{21}$$

Recall that the pricing equations imply:

$$\frac{\tilde{\rho}_{D,t}}{\mu_{D,t}} = \frac{\varphi_t}{\tilde{z}_D}, \qquad \frac{Q_t \tilde{\rho}_{X,t}}{\mu_{X,t}^h} = \frac{\tau_t \varphi_t}{\tilde{z}_{X,t}},$$

and labor market clearing requires:

$$l_t h_t = N_{D,t}\frac{\tilde{y}_{D,t}}{Z_t \tilde{z}_D} + N_{X,t}\frac{\tilde{y}_{X,t}}{Z_t \tilde{z}_{X,t}}\tau_t + N_{E,t}\frac{f_{E,t}}{Z_t} + N_{X,t}\frac{f_{X,t}}{Z_t}.$$

It follows that home's net foreign assets entering period $t+1$ are determined by the gross interest income on the assets position entering period t plus the difference between home's total production and total demand (or absorption) of consumption:

$$a_{t+1} + Q_t a_{*,t+1} = \frac{1+i_t}{1+\pi_{C,t}} a_t + Q_t \frac{1+i_t^*}{1+\pi_{C,t}^*} a_{*,t} + N_{D,t}\tilde{\rho}_{D,t}\tilde{y}_{D,t} + Q_t N_{X,t}\tilde{\rho}_{X,t}\tilde{y}_{X,t} - Y_t^C. \tag{22}$$

A similar equation holds in Foreign:

$$a_{*,t+1}^* + \frac{1}{Q_t} a_{t+1}^* = \frac{1+i_t^*}{1+\pi_{C,t}^*} a_{*t}^* + \frac{1}{Q_t}\frac{1+i_t}{1+\pi_{C,t}} a_t^* + N_{D,t}^*\tilde{\rho}_{D,t}^*\tilde{y}_{D,t}^* + \frac{1}{Q_t} N_{X,t}^*\tilde{\rho}_{X,t}^*\tilde{y}_{X,t}^* - Y_t^{*C}. \tag{23}$$

Now, multiply equation (23) by Q_t, subtract the resulting equation from (22) and use the bond market clearing conditions $a_{t+1} + a_{t+1}^* = 0 = a_{*,t+1}^* + a_{*,t+1}$ in all periods. It follows that:

$$a_{t+1} + Q_t a_{*,t+1}^* = \frac{1+i_t}{1+\pi_{C,t}} a_t + Q_t \frac{1+i_t^*}{1+\pi_{C,t}^*} a_{*,t} + \tag{24}$$

$$+\frac{1}{2}\left[N_{D,t}\tilde{\rho}_{D,t}\tilde{y}_{D,t} + Q_t N_{X,t}\tilde{\rho}_{X,t}\tilde{y}_{X,t} - Q_t N_{D,t}^*\tilde{\rho}_{D,t}^*\tilde{y}_{D,t}^* - N_{X,t}^*\tilde{\rho}_{X,t}^*\tilde{y}_{X,t}^*\right] - \frac{1}{2}\left(Y_t^C - Q_t Y_t^{C*}\right). \tag{25}$$

This is the familiar result that net foreign assets depend positively on the cross-country differential in production of final consumption output and negatively on relative absorption.

Notice next that home absorption of consumption must equal absorption of consumption output from home firms and output from foreign firms:

$$Y_t^C = N_{D,t}\tilde{\rho}_{D,t}\tilde{y}_{D,t} + N_{X,t}^*\tilde{\rho}_{X,t}^*\tilde{y}_{X,t}^*,$$

where we used the fact that $\rho_{X,t}^* = Q_t \rho_{D,t}^*$. Similarly,

$$Y_t^{C*} = N_{D,t}^*\tilde{\rho}_{D,t}^*\tilde{y}_{D,t}^* + N_{X,t}\tilde{\rho}_{X,t}\tilde{y}_{X,t},$$

Substituting these results into equation (24) yields net foreign assets as a function of interest income on the initial asset position and the trade balance:

$$a_{t+1}+Q_t a^*_{*,t+1}=\frac{1+i_t}{1+\pi_{C,t}}a_t+Q_t\frac{1+i^*_t}{1+\pi^*_{C,t}}a_{*,t}+Q_t N_{X,t}\tilde{\rho}_{X,t}\tilde{y}_{X,t}-N^*_{X,t}\tilde{\rho}^*_{X,t}\tilde{y}^*_{X,t}.$$

D Equilibrium Conditions and Ramsey Optimal-Policy

Table A.1 summarizes the key equilibrium conditions of the model. We rearranged some equations appropriately for transparency of comparison to the planner's optimum, which we will use to build intuition for the tradeoffs facing the Ramsey policymaker. The table contains 25 equations that determine 25 endogenous variables of interest: $C_t, \tilde{\rho}_{D,t}, l_t, h_t, V_t, N_{D,t}, w_t/P_t, \tilde{z}_{X,t}, \pi_{w,t}, \pi_{C,t}, i_{t+1}, a_{t+1}$, their foreign counterparts, and Q_t. (Other variables that appear in the table are determined as described above.)

Let $\{\Lambda_{1,t}, ..., \Lambda_{23,t}\}_{t=0}^{\infty}$ be the Lagrange multiplier associated to the equilibrium conditions in Table A.1 (excluding the two interest-rate setting rules).[1] The Ramsey problem consists in choosing:

$$\{C_t, C^*_t, \tilde{\rho}_{D,t}, \tilde{\rho}^*_{D,t}, l_t, l^*_t, h_t, h^*_t, V_t, V^*_t, N_{D,t}, N^*_{D,t}, J_t, J^*_t, \tilde{z}_{X,t}, \tilde{z}^*_{X,t}, \pi_{w,t},$$
$$\pi^*_{w,t}, \pi_{C,t}, \pi^*_{C,t}, i_{t+1}, i^*_{t+1}, a_{t+1}, a^*_{*,t+1}, Q_t, \Lambda_{1,t}, ..., \Lambda_{23,t}\}_{t=0}^{\infty}.$$

to maximize:

$$E_0\sum_{t=0}^{\infty}\beta^t\left\{\frac{1}{2}\left[u(C_t)-l_t v(h_t)\right]+\frac{1}{2}\left[u(C^*_t)-l^*_t v(h^*_t)\right]\right\}, \tag{26}$$

subject to the constraints in Table A.1 (excluding the interest rate rules).[2]

E Model Properties

Table A.2 presents model-implied, HP-filtered second moments (normal fonts). Bold fonts denote data moments, where cross-country correlations are averages of bilateral GDP and consumption correlations between the U.S. and its four largest trading partners during the period considered for the model calibration (Canada, Japan, Germany and UK).

The model correctly reproduces the volatility of U.S. consumption, investment, and real wages

[1] We assume that the other variables that appear in the table have been substituted out by using the appropriate equations and definitions above.

[2] In the primal approach to Ramsey policy problems described by Lucas and Stokey (1983), the competitive equilibrium is expressed in terms of a minimal set of relations involving only real allocations. In the presence of sticky prices and wages, it is impossible to reduce the Ramsey planner's problem to a maximization problem with a single implementability constraint.

relative to GDP. Moreover, it generates a negative Beveridge curve, and all the first-order autocorrelations are in line with the data.[3] Investment volatility is lowered relative to the excessive volatility generated by a standard IRBC framework because product creation requires hiring new workers. This process is time consuming due to search and matching frictions in the labor market, dampening investment dynamics. In contrast, consumption is more volatile than in traditional models as shocks induce larger and longer-lasting income effects.

The model is quite successful in matching the cyclical properties of trade data: imports and exports are more volatile than GDP, net exports are countercyclical and the volatility of the trade balance relative to GDP is in line with the data. The model can also reproduce a ranking of cross-country correlations that is a challenge for standard IRBC models: GDP correlation is larger than consumption correlation. As shown in Figure 1 in the main text, an increase in Home productivity generates Foreign expansion through trade linkages, as demand-side complementarities more than offset the effect of resource shifting to the more productive economy. Moreover, absent technology spillovers, Foreign consumers have weaker incentives to increase consumption on impact, which reduces cross-country consumption correlation.

F Social Planner Allocation and Inefficiency Wedges

The Ramsey planner uses its policy instruments (the Home and Foreign interest rates) to address the consequences of a set of distortions that exist in the market economy. To understand these distortions and the tradeoffs they create for optimal policy, it is instructive to compare the equilibrium conditions of the market economy to those implied by the solution to a first-best, optimal planning problem. This allows us to define inefficiency wedges for the market economy (relative to the planner's optimum) and describe Ramsey policy in terms of its implications for these wedges.

F.1 Planner Economy

Here we derive the first-best allocation chosen by a benevolent social planner for the world economy, summarized in Table A.3. The social planner chooses:

$$\{C_t, C_t, l_t, l_t^*, h_t, h_t^*, V_t, V_t^*, Y_{D,t}, Y_{D,t}^*, Y_{X,t}, Y_{X,t}^*, \tilde{z}_{X,t}, \tilde{z}_{X,t}^*, N_{D,t+1}, N_{D,t+1}^*\}_{t=0}^{\infty},$$

[3] The close match between data- and model-implied real wage moments provides indirect support for our calibration of the nominal wage adjustment cost.

to maximize the welfare criterion (26) subject to six constraints (three for each economy). We assume that the productivity distribution $G(z)$, sunk costs of product creation $N_{E,t}f_{E,t}$, fixed export costs $N_{X,t}f_{X,t}$, per-unit iceberg trade costs τ_t, and the cost of vacancy posting κV_t are all features of technology—the technology for product and job creation—that characterizes also the planner's environment.

The first constraint in the social planner's problem is that intermediate inputs are used to produce final goods, create new product lines and pay for fixed export costs:

$$Z_t l_t = N_{D,t}^{\frac{1}{\theta-1}} \frac{Y_{D,t}}{\tilde{z}_D} + N_{X,t}^{\frac{1}{\theta-1}} \frac{\tau_t Y_{X,t}}{\tilde{z}_{X,t}} + \left(\frac{N_{D,t+1}}{1-\delta} - N_{D,t} \right) f_{E,t} + N_{X,t} f_{X,t}, \tag{27}$$

where

$$\frac{N_{X,t}}{N_{D,t}} \equiv 1 - G(z_{X,t}) = \left(\frac{z_{\min}}{\tilde{z}_{X,t}} \right)^{-k_p} \alpha^{\frac{k_p}{\theta-1}} N_{D,t}$$

as discussed in the main text. We denote the Lagrange multiplier associated to the constraint (27) with ϖ_t, which corresponds to the social marginal cost of producing an extra unit of intermediate output.

The second constraint is that total output can be used for consumption and vacancy creation:

$$C_t + \kappa V_t = \left[Y_{D,t}^{\frac{\phi-1}{\phi}} + Y_{X,t}^{*\frac{\phi-1}{\phi}} \right]^{\frac{\phi}{\phi-1}}. \tag{28}$$

The Lagrange multiplier associated to this constraint, ξ_t, represents the social marginal utility of consumption resources. In the social planner's environment, $Y_t^C = C_t + \kappa V_t$.

Finally, the third constraint is that the stock of labor in the current period is equal to the number of workers that were not exogenously separated plus previous period matches that become productive in the current period:

$$l_t = (1-\lambda) l_{t-1} + \chi (1 - l_{t-1})^{1-\varepsilon} V_{t-1}^{\varepsilon}. \tag{29}$$

The Lagrange multiplier associated to this constraint, ζ_t, denotes the real marginal value of a match to society.

The first-order condition for consumption implies that $\xi_t = u_{C,t}$. Defining the real exchange rate as $Q_t \equiv \xi_t^* / \xi_t$, the planner's outcome is characterized by optimal risk sharing: $Q_t = u_{C,t}^* / u_{C,t}$.

The demand schedules for Home output are obtained by combining the first-order conditions with respect to $Y_{D,t}$, $Y_{X,t}$, $Y_{D,t}^*$ and $Y_{X,t}^*$:

$$Y_{D,t} = \left[\left(\frac{\varpi_t}{\tilde{z}_D \xi_t} N_{D,t}^{\frac{1}{1-\theta}} \right)^{-\phi} \right] Y_t^C, \qquad Y_{X,t} = \left[\left(\frac{\varpi_t \tau_t}{\tilde{z}_{X,t} \xi_t^*} N_{X,t}^{*\frac{1}{1-\theta}} \right)^{-\phi} \right] Y_t^{C*}. \tag{30}$$

To facilitate the comparison between planned and market economy, we define the following relative prices for the planner's equilibrium: $\tilde{\rho}_{D,t} \equiv \varpi_t / (\tilde{z}_D \xi_t)$ and $\tilde{\rho}_{X,t} \equiv (\tau_t \varpi_t) / (\tilde{z}_{X,t} \xi_t^*)$. Analogous definitions hold for Foreign. Using the results in (30) and the analogs for Foreign output, it is possible to re-write equation (28) as:

$$1 = \tilde{\rho}_{D,t}^{1-\theta} N_{D,t}^{\frac{1-\phi}{1-\theta}} + \tilde{\rho}_{X,t}^{*1-\theta} N_{X,t}^{*\frac{1-\phi}{1-\theta}}.$$

The first-order condition for the average export-productivity, $\tilde{z}_{X,t}$, implies:

$$\tau_t Y_{X,t} N_{X,t}^{*\frac{1}{1-\theta}} \left[-\frac{1}{\tilde{z}_{X,t}^2} + \frac{k_p}{(\theta-1)\tilde{z}_{X,t}^2} \right] - k_p \frac{N_{X,t}}{\tilde{z}_{X,t}} f_{X,t} = 0.$$

Using $Y_{X,t} = \tilde{\rho}_{X,t}^{-\phi} N_{X,t}^{-\phi/(1-\theta)} Y_t^C$ we can rearrange the above expression, obtaining:

$$\tilde{\rho}_{X,t}^{-\phi} N_{X,t}^{\frac{\theta-\phi}{1-\theta}} Y_t^{C*} = \frac{(\theta-1)k_p}{[k_p - (\theta-1)]} \frac{\tilde{z}_{X,t}}{\tau_t} f_{X,t}.$$

The optimality condition for $N_{D,t+1}$ equates the cost of creating a new product to its expected discounted benefit:

$$f_{E,t} = \beta(1-\delta) E_t \left\{ \frac{\varpi_{t+1}}{\varpi_t} \left[f_{E,t+1} - \frac{N_{X,t+1}}{N_{D,t+1}} f_{X,t+1} + \frac{1}{1-\theta} \left(\frac{N_{D,t+1}^{\frac{\theta}{\theta-1}} Y_{D,t+1}}{\tilde{z}_D} + \frac{\tau_t N_{X,t+1}^{\frac{\theta}{\theta-1}} Y_{X,t+1}}{\tilde{z}_{X,t+1}} \right) \right] \right\}. \tag{31}$$

The average output produced by the representative of Home firm for the domestic market is $\tilde{y}_{D,t} \equiv N_{D,t}^{\theta/(\theta-1)} Y_{D,t}$. Analogously, the amount of output produced by the representative Home firm for the export market is $\tilde{y}_{X,t} \equiv N_{X,t}^{\theta/(\theta-1)} Y_{X,t}$. Finally, recall that $\varpi_t \equiv \tilde{\rho}_{D,t} \tilde{z}_D \xi_t = \tilde{\rho}_{X,t} \tilde{z}_{X,t} \xi_t^* / \tau_t$, and $\xi_t = u_{C,t}$. Therefore, equation (31) can be written as:

$$f_{E,t} = E_t \left\{ \beta_{t,t+1} \frac{\tilde{\rho}_{D,t+1}}{\tilde{\rho}_{D,t}} \left[f_{E,t+1} - \frac{N_{X,t+1}}{N_{D,t+1}} f_{X,t+1} + \frac{1}{1-\theta} \left(\frac{\tilde{y}_{D,t+1}}{\tilde{z}_D} + Q_t \frac{N_{X,t+1}}{N_{D,t+1}} \frac{\tilde{\rho}_{X,t+1}}{\tilde{\rho}_{D,t+1}} \frac{\tilde{y}_{X,t+1}}{\tilde{z}_D} \right) \right] \right\}. \tag{32}$$

The first-order conditions for vacancies and employment yield:

$$\frac{\kappa}{q_t} = \beta E_t \left\{ \frac{\xi_{t+1}}{\xi_t} \left[\varepsilon \left(\frac{\varpi_{t+1}}{\xi_{t+1}} Z_{t+1} h_t - h_p \right) + [1 - \lambda - (1-\varepsilon) \iota_{t+1}] \frac{\kappa}{q_{t+1}} \right] \right\}, \tag{33}$$

where $q_t \equiv M_t/V_t = \chi \left[(1-l_t)/V_t\right]^{1-\varepsilon}$ is the probability of filling a vacancy implied by the matching function $M_t = \chi \left(1-l_t\right)^{1-\varepsilon} V_t^{\varepsilon}$, and $\iota_t \equiv M_t/\left(1-l_t\right) = \chi \left[V_t/(1-l_t)\right]^{\varepsilon}$ is the probability for a worker to find a job. By applying the usual transformations, equation (33) can be written as:

$$\frac{\kappa}{q_t} = \beta E_t \left\{ \frac{u_{C,t+1}}{u_{C,t}} \left[\varepsilon \left(\tilde{\rho}_{D,t+1} \tilde{z}_D Z_{t+1} h_t - h_p \right) + \left[1 - \lambda - (1-\varepsilon)\, \iota_{t+1}\right] \frac{\kappa}{q_{t+1}} \right] \right\}. \tag{34}$$

The expected cost of filling a vacancy κ/q_t must be equal to its (social) expected benefit. The latter is given by the average value of output produced by one worker net of the disutility of labor, augmented by the continuation value of the match. Finally, the first-order condition for hours implies $v_{h,t} = \varpi_t Z_t$. Table A.3 summarizes the equilibrium conditions for the planned economy.

F.2 Inefficiency Wedges

Here we derive the inefficiency wedges that characterize the market economy by comparing the equilibrium allocation in the decentralized economy (Table A.1) to the one chosen by the social planner (Table A.3).

The presence of price and wage stickiness, firm monopoly power, positive unemployment benefits, and incomplete markets induces ten sources of distortion (summarized in Table A.4) in the market economy. These distortions affect three margins of adjustment and the resource constraint for consumption output in the decentralized economy:

Product Creation Margin: Comparing the term in square brackets in equation (9) in Table A.1 to the term in square brackets in equation (9) in Table A.3 implicitly defines the inefficiency wedge along the market economy's product creation margin. Specifically, subtracting the term for the planned outcome from that for the market economy and scrolling time indexes backward by one period allows us to define:

$$\Sigma_{PC,t} = E_t \left\{ \tilde{\beta}_{t,t+1} \frac{\tilde{\rho}_{D,t+1}}{\tilde{\rho}_{D,t}} \left[\begin{array}{c} \Upsilon_{\mu_{D,t+1}} \left(\frac{f_{E,t+1}}{f_{E,t}} - \frac{N_{X,t+1}}{N_{D,t+1}} \frac{f_{X,t+1}}{f_{E,t}} \right) \\ + \frac{1}{(\theta-1) f_{E,t}} \left(\Upsilon_{\mu_{D,t+1}} \frac{\tilde{y}_{D,t+1}}{\tilde{z}_D} + \frac{N_{X,t+1}}{N_{D,t+1}} \frac{Q_{t+1} \tilde{\rho}_{X,t+1}}{\tilde{\rho}_{D,t+1}} \frac{\tilde{y}_{X,t+1}}{\tilde{z}_D} \Upsilon_{\mu_{X,t+1}} \right) \end{array} \right] \right\}.$$

The wedge $\Sigma_{PC,t}$ is induced by the presence of sticky prices which result in inefficient time-variation and lack of synchronization of domestic and export markups: $\Upsilon_{\mu_{D,t}} \equiv \mu_{D,t-1}/\mu_{D,t} - 1$ and $\Upsilon_{\mu_{X,t}} \equiv \mu_{D,t}/\mu_{X,t}^h - 1$. Absent sticky prices ($\Upsilon_{\mu_{D,t}} = \Upsilon_{\mu_{X,t}} = 0$), the product creation wedge $\Sigma_{PC,t}$ is zero.

Job creation margin: Comparing the term in square brackets in equation (11) in Table A.1 to the term in square brackets in equation (11) in Table A.3 implicitly defines the inefficiency wedge along the market economy's job creation margin. As for the product creation wedge, subtracting the term for the planned outcome from that for the market economy and scrolling time indexes backward by one period yields:

$$\Sigma_{JC,t} \equiv \frac{q_{t-1}}{\kappa} \left[\left(\varphi_t Z_t h_t - \frac{w_t}{P_t} h_t - \frac{\vartheta}{2} \pi_{w,t}^2 \right) - \varepsilon \left(\rho_{D,t} Z_t h_t - \frac{v(h_t)}{u_{C,t}} \right) \right] + \frac{q_{t-1}}{q_t} (1-\varepsilon) \iota_t. \quad (35)$$

The wedge $\Sigma_{JC,t}$ is a combination of various distortions. Monopoly power in the final sector distorts the job creation decision by inducing a suboptimally low return from vacancy posting, captured by $\Upsilon_{\varphi,t} \equiv 1/\mu_{D,t}$. Failure of the Hosios condition (for which equality of the firm's bargaining share and the vacancy elasticity of the matching function is necessary for efficiency) is an additional distortion in this margin, measured by $\Upsilon_{\eta,t} \equiv \eta_t - \varepsilon$. This is affected both by the flexible-wage value of the bargaining share (η, which can be different from ε) and the presence of wage stickiness, which induces time variation of η_t. Sticky wages are sufficient to generate a wedge between private and social returns to vacancy posting. Moreover, they distort job creation also by affecting the outside option of firms through an additional term $\Upsilon_{\pi_w,t} \equiv \vartheta \pi_{w,t}^2/2$. Finally, unemployment benefits increase the workers' outside option above its efficient level: $\Upsilon_{b,t} \equiv b$. When $\Upsilon_{\varphi,t} = \Upsilon_{\eta,t} = \Upsilon_{b,t} = \Upsilon_{\pi_w,t} = 0$, the real wage is determined by

$$\frac{w_t}{P_t} h_t = \varepsilon \frac{v(h_t)}{u_{C,t}} + (1-\varepsilon) \rho_{D,t} Z_t h_t + \kappa (1-\varepsilon) \iota_t / q_t,$$

and $\Sigma_{JC,t} = 0$.

Labor supply margin: With endogenous labor supply, monopoly power in product markets, $\Upsilon_{\varphi,t} \equiv \left(1/\mu_{D,t}\right) - 1$, induces a misalignment of relative prices between consumption goods and leisure. This is the distortion that characterizes standard New Keynesian models without labor market frictions. The associated wedge $\Sigma_{h,t} \equiv \Upsilon_{\varphi,t}$, which is time-varying for the presence of sticky prices.

Cross-country risk sharing margin: Incomplete markets imply inefficient risk sharing between Home and Foreign households, resulting in the distortion $\Upsilon_{Q,t} \equiv \left(u_{C^*,t}/u_{C,t}\right)/Q_t$. The departure of relative consumption from the perfect risk sharing outcome is also affected by the costs of adjusting bond holdings (the distortion $\Upsilon_{a,t} \equiv \psi a_{t+1} + \psi a_{*,t+1}$ and its Foreign mirror image in the Euler equations for Home and Foreign holdings of bonds). We summarize the combined effect of these distortions with the financial inefficiency wedge $\Sigma_{RS,t} \equiv \left(u_{C^*,t}/u_{C,t}\right)/Q_t = \Upsilon_{Q,t}$. Efficiency along this margin requires $\Sigma_{RS,t} = 1$.

Consumption resource constraint: Sticky prices and wages imply diversion of resources from consumption and creation of new product lines and vacancies, with the distortions $\Upsilon_{\pi_w,t} \equiv \vartheta\pi^2_{w,t}/2$, $\Upsilon_{\pi_D,t} \equiv \nu\pi^2_{D,t}/2$ and $\Upsilon_{\pi_X,t} \equiv \nu\pi^2_{X,t}/2$. The associated wedge (defined by $\Sigma_{Y^C,t} \equiv \Upsilon_{\pi_w,t} + \Upsilon_{\pi_D,} + \Upsilon_{\pi_X,t}$) is zero under flexible wages and prices.

The market allocation is efficient only if all the distortions and associated inefficiency wedges are zero at all points in time. Since we abstract from optimal fiscal policy and focus on asymmetric shocks, it follows that we work in a second-best environment in which the efficient allocation cannot be achieved. In this second-best environment, the Ramsey central bank optimally uses its leverage on the economies via the sticky-price and sticky-wage distortions, trading off its costs (including the resource costs) against the possibility of addressing the distortions that characterize the market economy under flexible wages and prices.

G Additional Sensitivity Analysis

G.1 Optimal-Trend Inflation: Robustness Analysis

Table A.5 reports the optimal (annualized) inflation rate for alternative models and for different levels of trade integration (i.e., for different values of the iceberg trade costs). The "Baseline" scenario refers to the model presented in Section 2 in the main text. The "No Wage Rigidity" scenario assumes flexible wages, i.e., the wage-adjustment cost is equal to zero ($\vartheta = 0$). The "No Price Stickiness" model assumes flexible prices, i.e., the price-adjustment cost is equal to zero ($\nu = 0$). The "Calvo Price Stickiness" scenario refers to a version of the model that assumes staggered price adjustment in the final-goods sector (rather than a quadratic adjustment cost). We present the equilibrium conditions of this alternative model in Section G.3 below. We set the probability of not readjusting prices to a conventional value of 0.75. Finally, the "New-Keynesian Model" corresponds to a benchmark New Keynesian model that features staggered price and wage adjustment. We present the equilibrium conditions of this model in Section I below. In this case, we set the probability of not readjusting prices and wages to 0.75.

Table A.5 shows that what motivates a positive optimal long-run inflation rate is wage stickiness and not price rigidities. In fact, absent wage stickiness, the central bank loses its ability to affect job creation and the optimal inflation rate is $\pi = 0$ under both Rotemberg and Calvo price-setting frictions. The reason behind this result is that the Ramsey-optimal policy engineers positive net inflation to stimulate job creation through its leverage on the effective firm bargaining power. Once this channel of transmission is muted, the standard prescription of zero optimal long-run inflation that emerges in benchmark New Keynesian models is restored.

Both Rotemberg and Calvo price stickiness lower the optimal inflation rate in the presence of nominal wage rigidity. To see this, notice that with flexible prices (and sticky wages), $\pi = 2.44\%$ when trade linkages are weak, a higher figure relative to both Calvo and Rotemberg price stickiness. To summarize, the welfare costs of price-setting frictions—either due to a waste of productive resources (Rotemberg) or due to price dispersion (Calvo)—lower the central bank's incentive to use inflation to generate higher employment. Finally, the optimal long-run inflation target is zero in this benchmark New Keynesian model. Once again this result confirms it is the combination of wage rigidity and search-and-matching frictions that motivates a positive optimal long-run inflation rate.

G.2 Nominal Wage Indexation

We introduce nominal wage indexation by assuming that the real cost of changing nominal wages between period t and $t-1$ is given by

$$\frac{\vartheta}{2}\left(\frac{w_t}{w_{t-1}}\left(1+\bar{\pi}_t\right)^{-\iota_w}-1\right)^2,$$

where $\iota_w \in [0,1]$ measures the degree to which nominal wage adjustment is indexed to contemporaneous price inflation, $\bar{\pi}_t$. We assume $\bar{\pi}_t$ is equal to CPI inflation ($\bar{\pi}_{w,t} = \pi_t^C$) or, alternatively, to its data-consistent counterpart ($\bar{\pi}_t = \tilde{\pi}_t^C$).

The value of a match is now given by:

$$J_t = \varphi_t Z_t h_t - \frac{w_t}{P_t} h_t - \frac{\vartheta}{2}\Gamma_{w,t}^2 + E_t \beta_{t,t+1}(1-\lambda) J_{t+1},$$

where $\Gamma_{w,t} \equiv \left(w_t/w_{t-1}\right)\left(1+\bar{\pi}_t\right)^{-\iota_w} - 1$. The worker asset value of a match and the value of unemployment are unchanged. The Nash bargaining first-order condition implies:

$$\eta H_t \frac{\partial J_t}{\partial w_t} + (1-\eta) J_t \frac{\partial H_t}{\partial w_t} = 0,$$

where:

$$\frac{\partial J_t}{\partial w_t} P_t = -h_t - \vartheta \frac{\Gamma_{w,t}}{w_{t-1}^R} \bar{\pi}_t^{-\iota_w} (1+\pi_{C,t}) + (1-\lambda)\vartheta E_t \left[\beta_{t,t+1} \frac{\Gamma_{w,t+1}}{w_t^R} (1+\pi_{w,t+1}) \bar{\pi}_{t+1}^{-\iota_w} \right].$$

When $\iota_w = 0$, there is no wage indexation, which corresponds to the benchmark version of the model. When $\iota_w = 1$ (full indexation), the real cost of changing nominal wages is zero in steady state, since $\pi_w = \pi^C = \tilde{\pi}^C$. In the latter case, steady-state inflation no longer affects job creation, since the firm bargaining power is equal to the exogenous weight of firm surplus in the Nash bargaining problem. As discussed above, the implication of this result is that with $\iota_w = 1$ the Ramsey-optimal inflation is zero for any value of trade costs.

The empirical evidence concerning the degree of wage indexation has not converged to a punctual indication yet. For the U.S. economy, the estimation of medium-scale DSGE model typically yields figures that lie between 0.1 and 0.5. The estimates in Ascari, Branzoli, and Castelnuovo (2011), obtained using microdata, suggest an average figure around 0.5. Thus, we quantitatively explore the importance of wage indexation by setting $i_w = 0.5$. When trade linkages are weak, the Ramsey-optimal inflation target, π^R, remains well above 1 percent, since $\pi^R = 1.32$ percent. With weak trade linkages, the optimal long-run inflation target drops to $\pi^R = 1.08$ percent. Finally, none of the results about monetary policy stabilization and trade linkages are significantly affected by the introduction of nominal wage indexation.

G.3 Calvo-Price Setting

Here we present the equilibrium conditions for a version of the model that features staggered price setting. The only modification to the baseline model concerns the optimal pricing problem for final-goods producers.

In each period, there is a fixed probability $1-\alpha_p$ that a multi-product firm can adjust its price. As in the baseline model, we assume producer currency pricing (PCP). Each final producer sets $P_{D_j,t}$ and the domestic currency price of the export bundle, $P^h_{X_j,t}$. The price in the foreign market is $P_{X_j,t} = P^h_{X_j,t}/S_t$, where S_t is the nominal exchange rate.

Optimal Domestic and Export Price Consider the pricing problem of a firm that has the opportunity to adjust its price in a given period. Producer j chooses $\tilde{P}_{D_j,t}$ and $\tilde{P}^h_{X_j,t}$ to maximize the expected present discounted value of profits:

$$E_t \sum_{k=0}^{\infty} (\beta\alpha_p)^k \left(\frac{C_{t+k}}{C_t}\right)^{-\gamma} \left[\begin{array}{c} \frac{\tilde{P}_{D_j,t}}{P_{t+k}} Y_{D_j,t+k|t} + \frac{\tilde{P}^h_{X_j,t}}{P_{t+k}} Y_{X_j,t+k|t} \\ -\varphi_{D,t+k} Y_{D_j,t+k|t} - \tau_{t+k}\varphi_{X,t+k} Y_{X_j,t+k|t} \end{array}\right],$$

where the subscript $t+k|t$ indicates a variable in period $t+k$ conditional on the firm having last reset prices at time t and

$$Y_{D_j,t+k|t} = (1-\alpha_X)\left(\frac{P_{D_j,t}}{P_{D,t+k}}\right)^{-\theta_p} \left(\frac{P_{D,t+k}}{P_{t+k}}\right)^{-\phi} Y_{t+k},$$

$$\begin{aligned} Y_{X_j,t+k|t} &= \alpha_X \left(\frac{\tilde{P}_{X_j,t}}{P_{X,t+k}}\right)^{-\theta_p} \left(\frac{P_{X,t+k}}{P^*_{t+k}}\right)^{-\phi} Y^*_{t+k} \\ &= \alpha_X \left(\frac{\tilde{P}^h_{X_j,t}}{P_{t+k}}\right)^{-\theta_p} \left(\frac{P^h_{X,t+k}}{P_{t+k}}\right)^{\theta_p} \left(\frac{P_{X,t+k}}{P^*_{t+k}}\right)^{-\phi} Y^*_{t+k}. \end{aligned}$$

The first-order condition for $\tilde{P}_{D_j,t}$ implies:

$$\tilde{\rho}_{D_{j,t}} \equiv \frac{\tilde{P}_{D_j,t}}{P_t} = \frac{\theta_p}{\theta_p - 1} \frac{E_t \sum_{k=0}^{\infty} (\beta\alpha_p)^k C_{t+k}^{-\gamma} \varphi_{D,t+k} \Pi_{t,t+k}^{\theta_p} \Lambda_{D,t+k}}{E_t \sum_{k=0}^{\infty} (\beta\alpha_p)^k C_{t+k}^{-\gamma} \Pi_{t,t+k}^{\theta_p - 1} \Lambda_{D,t+k}},$$

where $\Lambda_{D,t+k} \equiv (1-\alpha_X)(P_{D,t+k}/P_{t+k})^{\theta_p - \phi} Y_{t+k}$ and $\Pi_{t,t+k} \equiv P_{t+k}/P_t$. The first-order condition for $\tilde{P}^h_{X_j,t}$ implies:

$$\tilde{\rho}^h_{X_{j,t}} \equiv \frac{\tilde{P}^h_{X_j,t}}{P_t} = \frac{\theta_p}{\theta_p - 1} \frac{E_t \sum_{k=0}^{\infty} (\beta\alpha_p)^k C_{t+k}^{-\gamma} \tau_{t+k}\varphi_{X,t+k} \Pi_{t,t+k}^{\theta_p} \Lambda_{X,t+k}}{E_t \sum_{k=0}^{\infty} (\beta\alpha_p)^k C_{t+k}^{-\gamma} \Pi_{t,t+k}^{\theta_p - 1} \Lambda_{X,t+k}},$$

where $\Lambda_{X,t+k} \equiv \alpha_X \left(P^h_{X,t+k}/P_{t+k}\right)^{\theta_p} \left(P_{X,t+k}/P^*_{t+k}\right)^{-\phi} Y^*_{t+k}$.

Aggregate Price Indexes The CPI index implies: $1 = (1-\alpha_X)\rho_{D,t}^{1-\phi} + \alpha_X \rho_{X,t}^{*1-\phi}$, where $\rho_{D,t} \equiv P_{D,t}/P_t$ and $\rho^*_{X,t} \equiv P^*_{X,t}/P_t$. In the symmetric equilibrium, the domestic price index is

$$\rho_{D,t}^{1-\theta_p} = \int_0^1 \rho_{D_j,t}^{1-\theta_p} dj = (1-\alpha_p)\tilde{\rho}_{D,t}^{1-\theta_p} + \alpha_p \left(\frac{\rho_{D,t-1}}{1+\pi_{C,t}}\right)^{1-\theta_p}.$$

The export price index in units of Home consumption, $\rho^h_{X,t} \equiv P^h_{X,t}/P_t$, is given by:

$$\left(\rho^h_{X,t}\right)^{1-\theta_p} = \int_0^1 \left(\rho^h_{X_j,t}\right)^{1-\theta_p} dj = (1-\alpha_p)\left(\tilde{\rho}^h_{X,t}\right)^{1-\theta_p} + \alpha_p \left(\frac{\rho^h_{X,t-1}}{1+\pi_{C,t}}\right)^{1-\theta_p}.$$

Resource Constraint The resource constraint implies that total output $Y^I_t = \int_0^1 Y^I_{jt} dj$ is equal to the sum of output to meet domestic demand, $Y_{D,t} = \int_0^1 Y_{D_j,t} dj$, and exports, $Y_{X,t} = \int_0^1 Y_{X_j,t} dj$:

$$Y^I_t = (1-\alpha_X)\left(\frac{P_{D,t}}{P_t}\right)^{\theta_p-\phi} Y_t \xi^p_{D,t} + (1-\alpha_p)\left(\frac{\tilde{P}^h_{X,t}}{P_t}\right)^{-\theta_p} + \alpha_p (1+\pi_{C,t})^{\theta_p} \xi^p_{X,t-1},$$

where $\xi^p_{D,t}$ captures domestic price dispersion:

$$\xi^p_{D,t} \equiv \int_0^1 \left(\frac{P_{D_j,t}}{P_t}\right)^{-\theta_p} dj = (1-\alpha_p)\left(\frac{\tilde{P}_{D,t}}{P_t}\right)^{-\theta_p} + \alpha_p (1+\pi_{C,t})^{\theta_p} \xi^p_{D,t-1},$$

and $\xi^p_{X,t}$ denotes export price dispersion:

$$\xi^p_{X,t} \equiv \int_0^1 \left(\frac{P^h_{X_j,t}}{P_t}\right)^{-\theta_p} dj = (1-\alpha_p)\left(\frac{\tilde{P}^h_{X,t}}{P_t}\right)^{-\theta_p} + \alpha_p (1+\pi_{C,t})^{\theta_p} \xi^p_{X,t-1}.$$

H Steady-State Analysis

Export Productivity Cutoff

Consider the Euler equation for product creation in steady state:

$$\varphi f_E = (1-\delta)\beta\left[\varphi\left(f_E - \frac{N_X}{N_D} f_X\right) + \frac{1}{\theta-1}\left(\varphi_D \frac{Y_D}{N_D} + \tau\varphi_X \frac{Y_X}{N_X}\frac{N_X}{N_D}\right)\right].$$

Let $\varsigma_{xd} \equiv N_X/N_D = (z_{\min}/\tilde{z}_{X,t})^{-k_p} \alpha^{k_p/(\theta-1)}$, where, as in the main text, $\alpha \equiv k_p/(k_p-\theta+1)$. Using these relationships, the above expression can be written as

$$\varphi f_E = (1-\delta)\beta\left[\varphi(f_E - \varsigma_{xd} f_X) + \frac{\varsigma_{xd}}{\theta-1}\left(\varphi_D \frac{Y_D}{N_X} + \tau\varphi_X \frac{Y_X}{N_X}\right)\right]. \tag{36}$$

Next, notice in the symmetric steady state, the following two properties are satisfied:

$$\varphi_D = \varphi_X \varsigma_{xd}^{1/(\theta-1)} \frac{\tilde{z}_X}{\tilde{z}_D}, \tag{37}$$

$$Y_D = \left(\frac{1}{\tau}\frac{\varphi_D}{\varphi_X}\right)^{-\phi} Y_X. \tag{38}$$

Proof. Since $\varphi_D = N_D^{1/(1-\theta)}\varphi/\tilde{z}_D$ and $\varphi_X = N_X^{1/(1-\theta)}\varphi/\tilde{z}_X$, it follows that

$$\varphi_D = \varphi_X \varsigma_{xd}^{1/(\theta-1)} \frac{\tilde{z}_X}{\tilde{z}_D}.$$

In addition, recall that $Y_D = \rho_D^{-\phi} Y^C$ and $Y_X = \rho_X^{-\phi} Y^{C*}$. In a symmetric steady state, the latter expression implies $Y^C = (P_X/P^*)^{\phi} Y_X$. Moreover, $P_{X,t} = P_{X,t}^h$. Combining these two results, we obtain

$$Y_D = \left(\frac{\rho_D}{\rho_X^h}\right)^{-\phi} Y_X.$$

Optimal pricing implies that $\rho_D = \mu_D \varphi_D$ and $\rho_X^h = \rho_X = \tau \mu_X^h \varphi_X$. Since in the symmetric steady state $\mu_D = \mu_X^h$, we finally obtain:

$$\frac{\rho_D}{\rho_X} = \frac{1}{\tau_t}\frac{\mu_{D,t}\varphi_D}{\mu_{X,t}^h \varphi_X} = \frac{1}{\tau}\frac{\varphi_D}{\varphi_X}.$$

■

By combining (37) and (38), equation (38) can be written as:

$$\begin{aligned}
\varphi_D Y_D &= \varphi_X \varsigma_{xd}^{1/(\theta-1)} \frac{\tilde{z}_X}{\tilde{z}_D} \left(\frac{1}{\tau}\frac{\varphi_D}{\varphi_X}\right)^{-\phi} Y_X \\
&= \varphi_X \varsigma_{xd}^{1/(\theta-1)} \frac{\tilde{z}_X}{\tilde{z}_D} \left(\varsigma_{xd}^{1/(\theta-1)} \frac{\tilde{z}_X}{\tilde{z}_D}\frac{1}{\tau}\right)^{-\phi} Y_X \\
&= \varphi_X \varsigma_{xd}^{(1-\phi)/(\theta-1)} \left(\frac{\tilde{z}_X}{\tilde{z}_D}\right)^{1-\phi} \tau^{\phi} Y_X.
\end{aligned}$$

Inserting the result above into (36) yields:

$$\varphi f_E = (1-\delta)\,\beta \left[\varphi\left(f_E - \varsigma_{xd} f_X\right) + \frac{\varsigma_{xd}}{\theta-1}\varphi_X \frac{Y_X}{N_X}\left(\varsigma_{xd}^{(1-\phi)/(\theta-1)}\left(\frac{\tilde{z}_X}{\tilde{z}_D}\right)^{1-\phi}\tau^{\phi} + \tau\right)\right].$$

Imposing the zero export profit condition:

$$\frac{k_p - (\theta-1)}{(\theta-1)k_p}\varphi_X \frac{Y_X}{N_X}\tau = f_X \varphi,$$

we have:

$$f_E = (1-\delta)\,\beta\left[f_E - \varsigma_{xd} f_X + \frac{\varsigma_{xd} k_p}{k_p-(\theta-1)}\frac{f_X}{\tau}\left(\varsigma_{xd}^{(1-\phi)/(\theta-1)}\left(\frac{\tilde{z}_X}{\tilde{z}_D}\right)^{1-\phi}\tau^{\phi}+\tau\right)\right].$$

The expression above can be further simplified as follows:

$$\frac{\zeta_0}{\varsigma_{xd}} = \varsigma_1\left(\varsigma_{xd}^{\frac{1-\phi}{\theta-1}}\left(\frac{\tilde{z}_X}{\tilde{z}_D}\right)^{1-\phi}\tau^{\phi}+\tau\right)-1,$$

where

$$\varsigma_0 \equiv \frac{f_E\left[1-(1-\delta)\,\beta\right]}{(1-\delta)\,\beta f_X} \text{ and } \varsigma_1 \equiv \frac{k_p}{\tau\left[k_p-(\theta-1)\right]}.$$

Using again the definition of $\varsigma_{xd} \equiv (z_{\min}/\tilde{z}_{X,t})^{-k_p}\,\alpha^{k_p/(\theta-1)}$, we obtain:

$$\tilde{z}_{X,t}^{-k_p}\zeta_0\zeta_2 = \varsigma_1\left(\zeta_4 \tilde{z}_{X,t}^{\frac{1-\phi}{1-\theta}(\theta-1-k_p)}+\tau\right)-1,$$

where

$$\zeta_2 \equiv z_{\min}^{k_p}\alpha^{\frac{k_p}{1-\theta}} \text{ and } \zeta_3 \equiv \tilde{z}_D^{\frac{(1-\phi)(k_p-\theta+1)}{(\theta-1)}}\tau^{\phi}.$$

Finally, let $\Delta_1 = \zeta_0\zeta_2$, $\Delta_2 = \varsigma_1\zeta_3$, and $\Delta_3 = \tau\varsigma_1 - 1$, to obtain the expression in the main text:

$$\Delta_1 \tilde{z}_{X,t}^{-k_p} - \Delta_2 \tilde{z}_{X,t}^{\frac{1-\phi}{1-\theta}(\theta-1-k_p)} - \Delta_3 = 0.$$

Job Creation

First notice that in a steady state with zero wage inflation the real wage is given by:

$$w^r = \eta\,(h_p+b)+(1-\eta)\,(\varphi_t Z_t + \kappa\varkappa)\,.$$

By substituting the wage equation into the job creation equation, and using $q=\chi\vartheta^{\varepsilon-1}$,we obtain:

$$\kappa\vartheta^{1-\varepsilon}\left[\frac{1}{\chi}-\beta\,(1-\lambda)\right]+\beta\eta\,(h_p+b)+(1-\eta)\kappa\varkappa = \eta\varphi Z. \tag{39}$$

Taking the total differential of equation (39) we obtain:

$$\frac{\partial\varkappa}{\partial\varphi} = \frac{\eta}{(1-\varepsilon)\left[\chi^{-1}-\beta\,(1-\lambda)\right]+1-\eta}.$$

Since our calibration implies that $\chi < 1$, then $\chi^{-1} > \beta(1-\lambda)$ and $\partial\varkappa/\partial\varphi > 0$.

Marginal Revenue

In the symmetric steady state $Q = 1$, $\tilde{\rho}_X = \tilde{\rho}_X^*$. and $N_X = N_X^*$. Moreover using $\phi = \theta$ (as implied by our calibration), we have:

$$
\begin{aligned}
1 &= \tilde{\rho}_D^{1-\theta} N_D + \tilde{\rho}_X^{1-\theta} N_X, \\
1 &= \left(\frac{\varphi}{\mu_D}\right)^{1-\theta} N_D \left[\tilde{z}_D^{\theta-1} + \left(\frac{\tilde{z}_X}{\tau}\right)^{\theta-1} \frac{N_X}{N_D}\right], \\
1 &= \left(\frac{\varphi}{\mu_D}\right)^{1-\theta} N_D \tilde{z}^{\theta-1}.
\end{aligned}
$$

It follows that $\varphi = (1/\mu_D) N_D^{1/(\theta-1)} \tilde{z}$.

I A Benchmark New Keynesian Model

We consider a two-country New Keynesian model that abstracts from search-and-matching frictions and endogenous producer entry. As in the baseline model, there are two vertically integrated production sectors in each country. In the upstream sector, perfectly competitive firms use labor to produce an intermediate input. In the downstream sector, representative monopolistically-competitive firms purchase intermediate input and produce differentiated varieties. The model features both price and wage rigidities as in Erceg, Henderson, and Levine (2000).

Here we limit ourselves to presenting the equilibrium conditions that are new relative to the baseline model.

I.1 Households and Wage Setting

Each economy is populated by a continuum of monopolistically competitive, infinitely-lived households indexed by $j \in [0,1]$. Household j maximizes the expected intertemporal utility function

$$
E_t \sum_{s=0}^{\infty} \beta^s \left[\frac{C_{j,t+s}^{1-\gamma}}{1-\gamma} - \frac{L_{j,t+s}^{1+\omega}}{1+\omega}\right],
$$

where $L_{j,t}$ is a differentiated labor service supplied by the household.

Intermediate-goods producers aggregate labor services into a composite labor input $L_t = \left[\int_0^1 (L_{j,t})^{(\theta_w-1)/\theta_w} dj\right]^{\theta_w/(\theta_w-1)}$, where $\theta_w > 0$ is the elasticity of substitution across differentiated labor inputs. The aggregate wage is given by $w_t^n = \left[\int_0^1 \left(w_{j,t}^n\right)^{1-\theta_w} dj\right]^{1/(1-\theta_w)}$.

Optimal Wage Households can readjust the wage in any given period with probability $1-\alpha_w$. When household j is able to reset its wage contract, the household maximizes expected utility over the states of the world in which the wage is in place:

$$E_t \sum_{k=0}^{\infty} (\beta\alpha_w)^k \left[\frac{C_{j,t+k|t}^{1-\gamma}}{1-\gamma} - \frac{L_{j,t+k|t}^{1+\omega}}{1+\omega}\right],$$

where the subscript $t+k|t$ indicates a variable in period $t+k$ conditional on the household having last reset the wage at time t. The household's budget constraint in period $t+k$ is:

$$A_{t+k+1|t}^j + S_{t+k}A_{*,t+k+1|t}^j + \frac{\psi}{2}P_{t+k}\left(\frac{A_{t+k+1|t}^j}{P_{t+k}}\right)^2 + \frac{\psi}{2}S_{t+k}P_{t+k}^*\left(\frac{A_{*,t+k+1|t}^j}{P_{t+k}^*}\right)^2 + P_{t+k}C_{j,t+k|t} =$$
$$= (1+i_{t+k})A_{t+k|t}^j + (1+i_{t+k}^*)A_{*,t+k|t}^j S_{t+k} + \tilde{w}_{j,t}^n L_{j,t+k|t} + T_{t+k|t}^A + T_{t+k|t}^i + T_{t+k|t}^f,$$

where the variables appearing in the budget constraint are defined as in Section 2 of the paper. When choosing the optimal wage $\tilde{w}_{j,t}^n$, the household takes into account the demand for its labor services: $L_{j,t+k|t} = \left(\tilde{w}_{j,t}^n / w_{t+k}^n\right)^{-\theta_w} L_{t+k}$. The first-order condition for $\tilde{w}_{j,t}^n$ implies the following optimal real wage, $w_t \equiv w_t^n/P_t$:

$$\tilde{w}_{j,t}^{1+\omega\theta_w} = \frac{\theta_w}{\theta_w - 1}\frac{\sum_{k=0}^{\infty}(\beta\alpha_w)^k E_t\left[L_{t+k}C_{t+k}^{-\gamma}\mathcal{MRS}_{t+k}w_{t+k}^{\theta_w(1+\omega)}\Pi_{t,t+k}^{\theta_w(1+\omega)}\right]}{\sum_{k=0}^{\infty}(\beta\alpha_w)^k E_t\left(L_{t+k}C_{t+k}^{-\gamma}w_{t+k}^{\theta_w}\Pi_{t,t+k}^{\theta_w-1}\right)},$$

where $\mathcal{MRS}_{t+k} \equiv L_{t+k}^{\omega}/C_{t+k}^{-\gamma}$ and $\Pi_{t,t+k} \equiv P_{t+k}/P_t$.

Aggregate Wage The aggregate real wage, $w_t \equiv w_t^n/P_t$, evolves according to

$$w_t^{1-\theta_w} = \int_0^{1-\alpha_w} \tilde{w}_t^{1-\theta_w} dj + \int_{1-\alpha_w}^1 \left(\frac{w_{t-1}}{1+\pi_{C,t}}\right)^{1-\theta_w} dj,$$

which implies:

$$w_t^{1-\theta_w} = (1-\alpha_w)\,\tilde{w}_t^{1-\theta_w} + \alpha_w\left(\frac{w_{t-1}}{1+\pi_{C,t}}\right)^{1-\theta_w}.$$

I.2 Final Goods Prices

In each country, there is a continuum of final-goods producers indexed by $j \in (0,1)$. Producer j faces the following domestic and export demand schedules:

$$Y_{D_j,t} = (1-\alpha_X)\left(\frac{P_{D_j,t}}{P_{D,t}}\right)^{-\theta_p}\left(\frac{P_{D,t}}{P_t}\right)^{-\phi} Y_t \tag{40}$$

$$Y_{X_j,t} = \alpha_X\left(\frac{P_{X_j,t}}{P_{X,t}}\right)^{-\theta_p}\left(\frac{P_{X,t}}{P_t^*}\right)^{-\phi} Y_t^*. \tag{41}$$

We now discuss the determination of the optimal price. In each period, there is a fixed probability $1-\alpha_p$ that a firm can adjust its price. We consider both producer currency pricing (PCP) and local currency pricing (LCP).

Producer Currency Pricing (PCP)

Under PCP, producer j sets the domestic price $P_{D_j,t}$ and let the export price be determined by $P_{X_j,t} = \tau_t P_{D_j,t}/S_t$. When resetting the price, producer j chooses $\tilde{P}_{D_j,t}$ to maximize the expected present discounted value of profits:

$$E_t\sum_{k=0}^{\infty}(\beta\alpha_p)^k\left(\frac{C_{t+k|k}}{C_{t+s}}\right)^{-\gamma}\left[\frac{\tilde{P}_{D_j,t}}{P_{t+k}}\left(Y_{D_j,t+k|t}+\tau_{t+k}Y_{X_j,t+k|t}\right)-\varphi_{t+k}\left(Y_{D_j,t+k|t}+\tau_{t+k}Y_{X_j,t+k|t}\right)\right].$$

The first-order condition implies

$$\tilde{\rho}_{D_j,t} \equiv \frac{\tilde{P}_{D_j,t}}{P_t} = \frac{\theta_p}{\theta_p-1}\frac{E_t\sum_{k=0}^{\infty}(\beta\alpha_p)^k C_{t+k}^{-\gamma}\varphi_{t+k}\Pi_{t,t+k}^{\theta_p}\Lambda_{t+k}}{E_t\sum_{k=0}^{\infty}(\beta\alpha_p)^k C_{t+k}^{-\gamma}\Pi_{t,t+k}^{\theta_p-1}\Lambda_{t+k}},$$

where $\Pi_{t,t+k} \equiv P_{t+k}/P_t$ and

$$\Lambda_{t+k} = (1-\alpha_X)\left(\frac{P_{D,t+k}}{P_{t+k}}\right)^{\theta_p-\phi} Y_{t+k} + \alpha_X\left(\frac{P_{D,t+k}}{P_{t+k}}\right)^{\theta_p-\phi}\frac{\tau_{t+k}^{1-\phi}}{Q_{t+k}^{-\phi}}Y_{t+k}^*.$$

Local Currency Pricing (LCP)

Under LCP, producer j chooses $\tilde{P}_{D_j,t}$ and $\tilde{P}_{X_j,t}$ to maximize the expected present discounted value of profits:

$$E_t \sum_{k=0}^{\infty} (\beta\alpha_p)^k \left(\frac{C_{t+k}}{C_t}\right)^{-\gamma} \left[\begin{array}{c} \left(\frac{\tilde{P}_{D_j,t}}{P_{t+k}}\right)^{1-\theta_p} \Lambda_{D,t+k} + Q_{t+k} \left(\frac{\tilde{P}_{X_j,t}}{P^*_{t+k}}\right)^{1-\theta_p} \Lambda_{X,t+k} \\ -\varphi_{t+k} \left[\left(\frac{\tilde{P}_{D_j,t}}{P_{t+k}}\right)^{-\theta_p} \Lambda_{D,t+k} - \tau_{t+k} \left(\frac{\tilde{P}_{X_j,t}}{P^*_{t+k}}\right)^{-\theta_p} \Lambda_{X,t+k} \right] \end{array} \right],$$

where $\Lambda_{D,t+k} = (1-\alpha_X)\left(P_{D,t+k}/P_{t+k}\right)^{\theta_p-\phi} Y_{t+k}$ and $\Lambda_{X,t+k} = \alpha_X \left(P_{X,t+k}/P^*_{t+k}\right)^{\theta_p-\phi} Y^*_{t+k}$.

The first-order condition for $\tilde{P}_{D_j,t}$ implies:

$$\tilde{\rho}_{D_j,t} \equiv \frac{\tilde{P}_{D_j,t}}{P_t} = \frac{\theta_p}{\theta_p - 1} \frac{E_t \sum_{k=0}^{\infty} (\beta\alpha_p)^k C_{t+k}^{-\gamma} \varphi_{t+k} \Pi_{t,t+k}^{\theta_p} \Lambda_{D,t+k}}{E_t \sum_{k=0}^{\infty} (\beta\alpha_p)^k C_{t+k}^{-\gamma} \Pi_{t,t+k}^{\theta_p-1} \Lambda_{D,t+k}}.$$

The first-order condition for $\tilde{P}_{X_j,t}$ yields:

$$\tilde{\rho}_{X_j,t} \equiv \frac{\tilde{P}_{X_j,t}}{P^*_t} = \frac{\theta_p}{\theta_p - 1} \frac{E_t \sum_{k=0}^{\infty} (\beta\alpha_p)^k C_{t+k}^{-\gamma} \varphi_{t+k} \tau_{t+k} \Pi^{*\theta_p}_{t,t+k} \Lambda_{X,t+k}}{E_t \sum_{k=0}^{\infty} (\beta\alpha_p)^k C_{t+k}^{-\gamma} Q_{t+k} \Pi^{*\theta_p-1}_{t,t+k} \Lambda_{X,t+k}}.$$

I.3 Aggregate Price Indexes

The CPI index implies: $1 = (1-\alpha_X)\,\rho_{D,t}^{1-\phi} + \alpha_X \rho_{X,t}^{*1-\phi}$, where $\rho_{D,t} \equiv P_{D,t}/P_t$ and $\rho^*_{X,t} \equiv P^*_{X,t}/P_t$. In turn, the domestic price index is given by

$$\rho_{D,t}^{1-\theta_p} = (1-\alpha_p)\,\tilde{\rho}_{D,t}^{1-\theta_p} + \alpha_p \rho_{D,t-1}^{1-\theta_p} (1+\pi_{C,t+1})^{\theta_p-1}.$$

Concerning the export price index, $\rho_{X,t} = (\tau_t/Q_t)\,\rho_{D,t}$ under PCP, while:

$$\rho_{X,t}^{1-\theta_p} = (1-\alpha_p)\,\tilde{\rho}_{X,t}^{1-\theta_p} + \alpha_p \rho_{X,t-1}^{1-\theta_p} \left(1+\pi^*_{C,t+1}\right)^{\theta_p-1}$$

under LCP.

I.4 Aggregate Resource Constraint

The aggregate resource constraint implies that total output $Y_t^I = \int_0^1 Y_{jt}^I dj$ is equal to the sum of output for domestic demand, $Y_{D,t} = \int_0^1 Y_{D_j,t} dj$, and exports, $Y_{X,t} = \int_0^1 Y_{X_j,t} dj$:

$$Y_t^I = \int_0^1 Y_{D_j,t} dj + \tau_t \int_0^1 Y_{X_j,t} dj = (1-\alpha_X)\, \rho_{D,t}^{-\phi} Y_t \xi_{D,t}^p + \tau_t \alpha_X \rho_{X,t}^{-\phi} Y_t^* \xi_{X,t}^p.$$

The term $\xi_{D,t}^p$ captures domestic price dispersion:

$$\xi_{D,t}^p \equiv \int_0^1 \left(\frac{P_{D_j,t}}{P_{D,t}}\right)^{-\theta_p} dj = (1-\alpha_p)\left(\frac{\tilde{\rho}_{D,t}}{\rho_{D,t}}\right)^{-\theta_p} + \alpha_p \left(\frac{\rho_{D,t-1}}{\rho_{D,t}}\right)^{-\theta_p} (1+\pi_{C,t})^{\theta_p} \xi_{D,t-1}^p.$$

The term $\xi_{X,t}^p$ captures export price dispersion. Under PCP, $\xi_{X,t}^p = \xi_{D,t}^p$. By contrast, under LCP:

$$\xi_{X,t}^p \equiv \int_0^1 \left(\frac{P_{X_j,t}}{P_{X,t}}\right)^{-\theta_p} dj = (1-\alpha_p)\left(\frac{\tilde{\rho}_{X,t}}{\rho_{X,t}}\right)^{-\theta_p} + \alpha_p \left(\frac{\rho_{X,t-1}}{\rho_{X,t}}\right)^{-\theta_p} (1+\pi_{C,t}^*)^{\theta_p} \xi_{X,t-1}^p.$$

I.5 Welfare

Define aggregate welfare as $\mathcal{W}_t \equiv \int_0^1 \mathcal{W}_{j,t} dj$, where the individual household welfare is given by

$$\mathcal{W}_{j,t} = \frac{C_t^{1-\gamma}}{1-\gamma} - \frac{L_{j,t}^{1+\omega}}{1+\omega} + \beta E_t \mathcal{W}_{j,t+1}.$$

Therefore, aggregate welfare can be written as:

$$\mathcal{W}_t \equiv \frac{C_t^{1-\gamma}}{1-\gamma} - \frac{1}{1+\omega} \int_0^1 L_{j,t}^{1+\omega} dj + \beta E_t \mathcal{W}_{t+1},$$

where $\mathcal{W}_{t+1} = \int_0^1 \mathcal{W}_{j,t+1} dj$. Finally, since $L_{j,t} = \left(w_{j,t}^n / w_t^n\right)^{-\theta_w} L_t$, we obtain:

$$\mathcal{W}_t \equiv \frac{C_t^{1-\gamma}}{1-\gamma} - \zeta_t^w \frac{L_t^{1+\omega}}{1+\omega} + \beta E_t \mathcal{W}_{t+1},$$

where the term ζ_t^w captures wage dispersion:

$$\zeta_t^w \equiv \int_0^1 \left(\frac{w_{j,t}^n}{w_t^n}\right)^{-\theta_w(1+\omega)} dj = (1-\alpha_w)\left(\frac{\tilde{w}_t}{w_t}\right)^{-\theta_w(1+\omega)} + \alpha_w (1+\pi_{w,t})^{\theta_w(1+\omega)} \zeta_{t-1}^w.$$

I.6 Calibration

Consistent with the benchmark model of Section 2, we set $\phi = \theta_p = 3.8$. We set the elasticity of substitution for the differentiated labor inputs at the conventional value $\eta = 6$. We set the Calvo probabilities of not readjusting prices and wages such that $\alpha_w = \alpha_p = 0.75$.

TABLE A.1: MODEL SUMMARY

$$1=\tilde{\rho}_{D,t}^{1-\theta}N_{D,t}^{\frac{1-\phi}{1-\theta}}+\tilde{\rho}_{X,t}^{*\,1-\theta}N_{X,t}^{*\,\frac{1-\phi}{1-\theta}} \tag{1}$$

$$1=\tilde{\rho}_{D,t}^{*\,1-\theta}N_{D,t}^{*\,\frac{1-\phi}{1-\theta}}+\tilde{\rho}_{X,t}^{1-\theta}N_{X,t}^{\frac{1-\phi}{1-\theta}} \tag{2}$$

$$\tilde{\rho}_{X,t}^{-\theta}N_{X,t}^{\frac{\theta-\phi}{1-\theta}}Y_t^{C*}=\frac{(\theta-1)}{k_p-(\theta-1)}\frac{\tilde{z}_{X,t}}{\tau_t}f_{X,t} \tag{3}$$

$$\tilde{\rho}_{X,t}^{*-\theta}N_{X,t}^{*\,\frac{\theta-\phi}{1-\theta}}Y_t^{C}=\frac{(\theta-1)}{k_p-(\theta-1)}\frac{\tilde{z}_{X,t}^*}{\tau_t^*}f_{X,t}^* \tag{4}$$

$$l_th_t=N_{D,t}\frac{\tilde{y}_{D,t}}{Z_t\tilde{z}_D}+N_{X,t}\frac{\tilde{y}_{X,t}}{Z_t\tilde{z}_{X,t}}\tau_t+N_{E,t}\frac{f_{E,t}}{Z_t}+N_{X,t}\frac{f_{X,t}}{Z_t} \tag{5}$$

$$l_t^*h_t^*=N_{D,t}^*\frac{\tilde{y}_{D,t}^*}{Z_t^*\tilde{z}_D}+N_{X,t}^*\frac{\tilde{y}_{X,t}^*}{Z_t\tilde{z}_{X,t}^*}\tau_t+N_{E,t}^*\frac{f_{E,t}^*}{Z_t^*}+N_{X,t}^*\frac{f_{X,t}^*}{Z_t^*} \tag{6}$$

$$l_t=(1-\lambda)l_{t-1}+q_{t-1}V_{t-1} \tag{7}$$

$$l_t^*=(1-\lambda)l_{t-1}^*+q_{t-1}^*V_{t-1}^* \tag{8}$$

$$1=E_t\left\{\tilde{\beta}_{t,t+1}\frac{\tilde{\rho}_{D,t+1}}{\tilde{\rho}_{D,t}}\left[\begin{array}{c}\frac{\mu_{D,t}}{\mu_{D,t+1}}\left(\frac{f_{E,t+1}}{f_{E,t}}-\frac{N_{X,t+1}}{N_{D,t+1}}\frac{f_{X,t+1}}{f_{E,t}}\right)+\\ \frac{1}{(\theta-1)f_{E,t}}\left(\frac{\mu_{D,t}}{\mu_{D,t+1}}\tilde{y}_{D,t+1}+\frac{N_{X,t+1}}{N_{D,t+1}}\frac{Q_{t+1}\tilde{\rho}_{X,t+1}\tilde{z}_{X,t+1}}{\tilde{\rho}_{D,t+1}\tilde{z}_D}\frac{\mu_{D,t+1}}{\mu_{X,t+1}^h}\tilde{y}_{X,t+1}\right)\end{array}\right]\right\} \tag{9}$$

$$1=E_t\left\{\tilde{\beta}_{t,t+1}^*\frac{\tilde{\rho}_{D,t+1}^*}{\tilde{\rho}_{D,t}^*}\left[\begin{array}{c}\frac{\mu_{D,t}^*}{\mu_{D,t+1}^*}\left(\frac{f_{E,t+1}^*}{f_{E,t}^*}-\frac{N_{X,t+1}^*}{N_{D,t+1}^*}\frac{f_{X,t+1}^*}{f_{E,t}^*}\right)+\\ \frac{1}{(\theta-1)f_{E,t}^*}\left(\frac{\mu_{D,t}^*}{\mu_{D,t+1}^*}\tilde{y}_{D,t+1}^*+\frac{N_{X,t+1}^*}{N_{D,t+1}^*}\frac{\tilde{\rho}_{X,t+1}^*\tilde{z}_{X,t+1}^*}{Q_{t+1}\tilde{\rho}_{D,t+1}^*\tilde{z}_D}\frac{\mu_{D,t+1}^*}{\mu_{X,t+1}^*}\tilde{y}_{X,t+1}^*\right)\end{array}\right]\right\} \tag{10}$$

$$1=E_t\left\{\beta_{t,t+1}\left[(1-\lambda)\frac{q_t}{q_{t+1}}+\frac{q_t}{\kappa}\left(\varphi_{t+1}Z_{t+1}h_{t+1}-\frac{w_{t+1}}{P_{t+1}}h_{t+1}-\frac{\vartheta}{2}\pi_{w,t+1}^2\right)\right]\right\} \tag{11}$$

$$1=E_t\left\{\beta_{t,t+1}^*\left[(1-\lambda)\frac{q_t^*}{q_{t+1}^*}+\frac{q_t^*}{\kappa}\left(\varphi_{t+1}^*Z_{t+1}^*h_{t+1}^*-\frac{w_{t+1}^*}{P_{t+1}^*}h_{t+1}^*-\frac{\vartheta}{2}\pi_{w,t+1}^{*2}\right)\right]\right\} \tag{12}$$

$$v_{h,t}/u_{C,t}=\varphi_tZ_t \tag{13}$$

$$v_{h,t}^*/u_{C,t}^*=\varphi_t^*Z_t^* \tag{14}$$

$$\pi_{w,t}=\frac{w_t^r}{w_{t-1}^r}\pi_{C,t} \tag{15}$$

$$\pi_{w,t}^*=\frac{w_t^{r*}}{w_{t-1}^{r*}}\pi_{C,t}^* \tag{16}$$

$$\begin{aligned}&\frac{w_t}{P_t}h_t=\eta_t\left(\frac{v(h_t)}{u_{C,t}}+b\right)+(1-\eta_t)\left(\varphi_tZ_th_t-\frac{\vartheta}{2}\pi_{w,t}^2\right)\\&+E_t\left\{\beta_{t,t+1}J_{t+1}\left[(1-\lambda)(1-\eta_t)-(1-\lambda-\iota_t)(1-\eta_{t+1})\frac{\eta_t}{\eta_{t+1}}\right]\right\}\end{aligned} \tag{17}$$

$$\begin{aligned}&\frac{w_t^*}{P_t^*}h_t^*=\eta_t^*\left(\frac{v(h_t^*)}{u_{C^*,t}}+b^*\right)+(1-\eta_t^*)\left(\varphi_t^*Z_t^*h_t^*-\frac{\vartheta}{2}\pi_{w,t}^{*2}\right)\\&+E_t\left\{\beta_{t,t+1}^*J_{t+1}^*\left[(1-\lambda)(1-\eta_t^*)-(1-\lambda-\iota_t^*)(1-\eta_{t+1}^*)\frac{\eta_t^*}{\eta_{t+1}^*}\right]\right\}\end{aligned} \tag{18}$$

$$1+i_{t+1}=(1+i_t)^{\varrho_i}\left[(1+i)\left(1+\tilde{\pi}_{C,t}\right)^{\varrho_\pi}\left(\tilde{Y}_{g,t}\right)^{\varrho_Y}\right]^{1-\varrho_i} \tag{19}$$

$$1+i_{t+1}^*=(1+i_t^*)^{\varrho_i}\left[(1+i^*)\left(1+\tilde{\pi}_{C,t}^*\right)^{\varrho_\pi}\left(\tilde{Y}_{g,t}^*\right)^{\varrho_Y}\right]^{1-\varrho_i} \tag{20}$$

$$(1+\psi a_{t+1})=(1+i_{t+1})\,E_t\beta_{t,t+1}\left(\frac{1}{1+\pi_{C,t+1}}\right) \tag{21}$$

$$\left(1-\psi a_{*,t+1}^*\right)=\left(1+i_{t+1}^*\right)E_t\beta_{t,t+1}\left(\frac{Q_{t+1}}{Q_t}\frac{1}{1+\pi_{C,t+1}^*}\right) \tag{22}$$

$$\left(1+\psi a_{*,t+1}^*\right)=\left(1+i_{t+1}^*\right)E_t\beta_{t,t+1}^*\left(\frac{1}{1+\pi_{C,t+1}^*}\right) \tag{23}$$

$$(1-\psi a_{t+1})=(1+i_{t+1})\,E_t\beta_{t,t+1}^*\left(\frac{Q_t}{Q_{t+1}}\frac{1}{1+\pi_{C,t+1}}\right) \tag{24}$$

$$a_{t+1}=\frac{1+i_t}{1+\pi_{C,t}}a_t-Q_t\frac{1+i_t^*}{1+\pi_{C,t}^*}a_{*,t}^*+N_{X,t}\tilde{\rho}_{D,t}\tilde{y}_{X,t}-N_{X,t}^*Q_t\tilde{\rho}_{D,t}^*\tilde{y}_{X,t}^* \tag{25}$$

TABLE A.2: BUSINESS CYCLE STATISTICS

Variable	$\sigma_{X_R^U}$		$\sigma_{X_R^U}/\sigma_{Y_R^U}$		1st Autocorr		$corr(X_{R,t}^U, Y_{R,t}^U)$	
Y_R	**1.71**	1.50	**1**	1	**0.83**	0.79	**1**	1
C_R	**1.11**	0.94	**0.64**	0.63	**0.70**	0.73	**0.67**	0.87
I_R	**5.48**	5.50	**3.20**	3.68	**0.89**	0.80	**0.87**	0.86
l	**0.97**	0.82	**0.56**	0.56	**0.88**	0.72	**0.79**	0.81
w_R	**0.91**	0.79	**0.52**	0.53	**0.91**	0.92	**0.56**	0.76
X_R	**5.46**	2.40	**3.18**	1.66	**0.67**	0.70	**0.18**	0.17
I_R	**4.35**	2.08	**2.54**	1.39	**0.32**	0.69	**0.70**	0.77
TB_R/Y_R	**0.25**	0.39	**0.14**	0.26	**0.43**	0.71	**-0.47**	-0.48
$corr(C_{R,t}, C_{R,t}^*)$	**0.44**	0.16						
$corr(Y_{R,t}, Y_{R,t}^*)$	**0.51**	0.26						

Bold fonts denote data moments, normal fonts denote model generated moments.

TABLE A.3: SOCIAL PLANNER

$$1=\tilde{\rho}_{D,t}^{1-\theta} N_{D,t} + \tilde{\rho}_{X,t}^{*1-\theta} N_{X,t}^* \tag{1}$$

$$1=\tilde{\rho}_{D,t}^{*1-\theta} N_{D,t}^* + \tilde{\rho}_{D,t}^{1-\theta} N_{X,t} \tag{2}$$

$$\tilde{\rho}_{X,t}^{-\phi} N_{X,t}^{\frac{\theta-\phi}{1-\theta}} {Y_t^*}^C = \frac{k_p(\theta-1)}{k_p-(\theta-1)} \frac{\tilde{z}_{X,t}}{\tau_t} f_{X,t} \tag{3}$$

$$\tilde{\rho}_{X,t}^{*-\phi} {N_{X,t}^*}^{\frac{\theta-\phi}{1-\theta}} Y_t^C = \frac{k_p(\theta-1)}{k_p-(\theta-1)} \frac{\tilde{z}_{X,t}^*}{\tau_t} f_{X,t}^* \tag{4}$$

$$l_t = N_{D,t} \frac{\tilde{y}_{D,t}}{Z_t \tilde{z}_D} + N_{X,t} \frac{\tilde{y}_{X,t}}{Z_t \tilde{z}_{X,t}} \tau_t + N_{E,t} \frac{f_{E,t}}{Z_t} + N_{X,t} \frac{f_{X,t}}{Z_t} \tag{5}$$

$$l_t^* = N_{D,t}^* \frac{\tilde{y}_{D,t}^*}{Z_t^* \tilde{z}_D} + N_{X,t}^* \frac{\tilde{y}_{X,t}^*}{Z_t \tilde{z}_{X,t}^*} \tau_t + N_{E,t}^* \frac{f_{E,t}^*}{Z_t^*} + N_{X,t}^* \frac{f_{X,t}^*}{Z_t^*} \tag{6}$$

$$l_t= (1-\lambda) l_{t-1} + q_{t-1} V_{t-1} \tag{7}$$

$$l_t^*= (1-\lambda) l_{t-1}^* + q_{t-1}^* V_{t-1}^* \tag{8}$$

$$1 = E_t \left\{ \tilde{\beta}_{t,t+1} \frac{\tilde{\rho}_{D,t+1}}{\tilde{\rho}_{D,t}} \left[\left(\frac{f_{E,t+1}}{f_{E,t}} - \frac{N_{X,t+1}}{N_{D,t+1}} \frac{f_{X,t+1}}{f_{E,t}} \right) + \frac{1}{(\theta-1) f_{E,t}} \left(\tilde{y}_{D,t+1} + \frac{N_{X,t+1}}{N_{D,t+1}} \frac{Q_{t+1} \tilde{\rho}_{X,t+1} \tilde{z}_{X,t+1}}{\tilde{\rho}_{D,t+1} \tilde{z}_D} \tilde{y}_{X,t+1} \right) \right] \right\} \tag{9}$$

$$1 = E_t \left\{ \tilde{\beta}_{t,t+1}^* \frac{\tilde{\rho}_{D,t+1}^*}{\tilde{\rho}_{D,t}^*} \left[\left(\frac{f_{E,t+1}^*}{f_{E,t}^*} - \frac{N_{X,t+1}^*}{N_{D,t+1}^*} \frac{f_{X,t+1}^*}{f_{E,t}^*} \right) + \frac{1}{(\theta-1) f_{E,t}^*} \left(\tilde{y}_{D,t+1}^* + (\frac{N_{X,t+1}^*}{N_{D,t+1}^*} \frac{\tilde{\rho}_{X,t+1}^* \tilde{z}_{X,t+1}^*}{Q_{t+1} \tilde{\rho}_{D,t+1}^* \tilde{z}_D} \tilde{y}_{X,t+1}^* \right) \right] \right\} \tag{10}$$

$$1 = E_t \left\{ \beta_{t,t+1} \left[\varepsilon \frac{q_t}{\kappa} \left(\rho_{D,t+1} Z_{t+1} h_{t+1} - \frac{v(h_{t+1})}{u_{C,t+1}} \right) + \left[1 - \lambda - (1-\varepsilon) \iota_{t+1} \right] \frac{q_t}{q_{t+1}} \right] \right\} \tag{11}$$

$$1 = E_t \left\{ \beta_{t,t+1}^* \left[\varepsilon \frac{q_t^*}{\kappa} \left(\rho_{D,t+1}^* Z_{t+1}^* h_{t+1}^* - \frac{v\left(h_{t+1}^*\right)}{u_{C^*,t+1}} \right) + \left[1 - \lambda - (1-\varepsilon) \iota_{t+1}^* \right] \frac{q_t^*}{q_{t+1}^*} \right] \right\} \tag{12}$$

$$v_{h,t} = \varpi_t Z_t \tag{13}$$

$$v_{h,t}^* = \varpi_t^* Z_t^* \tag{14}$$

$$Q_t = \frac{u_{C,t}^*}{u_{C,t}} \tag{15}$$

TABLE A.4: DISTORTIONS

$\Upsilon_{\mu_{D,t}} \equiv \frac{\mu_{D,t}}{\mu_{D,t-1}} - 1$	time varying domestic markups, product creation
$\Upsilon_{\mu_{X,t}} \equiv \frac{\mu^h_{X,t}}{\mu_{D,t}} - 1$	time varying export markups, product creation
$\Upsilon_{\varphi,t} \equiv \frac{1}{\mu_{D,t}} - 1$	monopoly power, job creation and labor supply
$\Upsilon_{\eta,t} \equiv \eta_t - \varepsilon$	failure of the Hosios condition*, job creation
$\Upsilon_{b,t} \equiv b$	unemployment benefits, job creation
$\Upsilon_{Q,t} \equiv \frac{u^*_{c,t}}{u_{c,t}} - Q_t$	incomplete markets, risk sharing
$\Upsilon_{a,t} \equiv \psi a_{t+1} + \psi a_{*,t+1}$	cost of adjusting bond holdings, risk sharing
$\Upsilon_{\pi_w,t} \equiv \frac{\vartheta}{2}\pi^2_{w,t}$	wage adjustment costs, resource constraint and job creation
$\Upsilon_{\pi_{D,t}} \equiv \frac{\nu}{2}\pi^2_{D,t}$	domestic price adjustment costs
$\Upsilon_{\pi_{X,t}} \equiv \frac{\nu}{2}\pi^2_{X,t}$	export price adjustment costs

* From sticky wages and/or $\eta \neq \varepsilon$.

TABLE A.5: ROBUSTNESS ANALYSIS

	Ramsey-Optimal Long-Run Inflation		
	$\frac{Trade}{GDP} = 0.1$	$\frac{Trade}{GDP} = 0.25$	$\frac{Trade}{GDP} = 0.35$
Baseline	1.45%	1.22%	1.10%
No Wage Stickiness	0%	0%	0%
No Price Stickiness	2.44%	2.15%	1.98%
Calvo Price Stickiness	1.72%	1.23%	1.11%
No Wage Rigidity and Calvo Price Stickiness	0%	0%	0%
New-Keynesian Model	0%	0%	0%

References

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[2] Erceg, C. J., D.W. Henderson, and A.T. Levin (2000): “Optimal Monetary Policy with Staggered Wage and Price Contracts,” *Journal of Monetary Economics* 46: 281-313.