The Commodity Currency Puzzle

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Job Market Paper
November 30, 2015
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Abstract

Commodity-exporting countries have persistently high real interest rates and currency excess returns. To explain this fact, I adapt a classic idea: labor cost disease, or the Balassa-Samuelson effect. Commodity booms raise wages in exporter countries, and thus make local goods and services less affordable, raising the cost of living (real exchange rate). Since the real exchange rate then moves procyclically with commodity prices, it inherits a commodity risk premium that resolves the puzzle. Using a rare-disaster setup, I show that a stochastic, international business cycle model, with local labor used as a factor of production, can quantitatively match observed commodity currency risk premia. The model’s predictions about the co-movement of commodity prices and exchange rates, the cross-section of risk premia, and the dynamics of labor costs, are also consistent with the data. Finally, to understand the impact of monetary policy, I build a New Keynesian, sticky-wage extension. Policy choices (for example, a credible peg) can reduce the risk premium on the real exchange rate, but at the cost of bigger output gaps.

JEL Codes: F31, F41, F44, G12, G15
Keywords: Currency risk premia, commodity currency, Balassa-Samuelson, exchange rates, carry trade, commodity trade, international monetary policy

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1 Introduction

Suppose the Australian dollar interest rate is 5%, and the U.S. dollar interest rate is 2%. How much of an excess return can one earn from borrowing in the U.S., converting currencies, and lending in Australia?

The classic theory of uncovered interest parity (UIP) says that currency expected excess returns must be 0%. The 3% interest spread should coincide with an expected 3% depreciation of the Australian dollar, which would net out to a 0% return for the investor.

A challenge to UIP can be found in commodity exporters, whose currencies have excess returns well above zero. Figure 1 shows the fact documented by Ready, Roussanov, and Ward (2013). Commodity importers like Japan and Switzerland have mean currency excess returns of zero, while commodity exporters such as Australia and Norway have mean currency excess returns as high as 3% per year. The authors show that a trading strategy that goes long commodity currencies and short non-commodity currencies earns a 4.5% excess return per year, with a Sharpe ratio of 0.5, both of which are comparable to the equity premium. Moreover, as shown in Figure 1, as much as a third of the differences in long-run average returns across major, floating-rate currencies can be explained by differences in commodity exposure.

This paper develops a theory to explain why commodity currencies outperform non-commodity currencies. My theory shows that exchange rates in commodity countries rise in good times and crash in bad times, so investments in these currencies earn a risk premium. Moreover, the economic mechanism behind this cyclicality is labor cost disease. Commodity booms raise wages in exporter countries, and thus make local, nontradable goods and services less affordable, raising the cost of living (real exchange rate). Because the real exchange rate moves procyclically with commodity prices, the currency inherits a commodity risk premium that resolves the puzzle.

This explanation is appealing because it falls out from a classic theory for the real exchange rate; namely, the Balassa-Samuelson theory that labor costs determine the exchange rate (Balassa 1964, Samuelson 1964). While the original Balassa-Samuelson papers focused on long-run productivity growth in the export sector as the main driver of labor costs, a rapid boom in commodity prices can raise “productivity” just as much, since export productivity is measured as what you can buy on the world market, per unit of labor. My idea is simply to build a stochastic
Balassa-Samuelson model, apply it to the case of a commodity exporter, and then compute asset prices.

An additional reason to favor this type of model is that models of cost disease have already been widely used to describe commodity exporters in the international macro literature (Bruno and Sachs 1982; Corden 1984). The literature on commodity currencies, in particular, uses stochastic models of this type (Chen and Rogoff 2005, Cashin, Céspedes, and Sahay 2004). I build on this literature by extending it to solve a puzzle in financial markets.

The paper’s central contribution is a model of the labor cost disease mechanism that makes asset pricing predictions for commodity exporters. This model is a dynamic, quantitative, two-country real business cycle model with production, a distinction between tradable and non-tradable goods, and a distinction between commodities and finished goods. I use a standard rare disaster parameterization to get a realistic amount of risk in the model.1

After laying out this model, I split my empirical analysis into two parts. First, I estimate key economic relationships that the model should fit. For example, in commodity exporters, real exchange rates and real commodity prices should be correlated; otherwise, there would be no reason for currencies to inherit commodity risk. Currency risk premia should be about as large as implied by their commodity risk exposure and commodity risk premia. Finally, real unit labor costs should co-move with commodity prices. All of these relationships need to be estimated, and this section covers the datasets, methods, and results.

Second, to check quantitative predictions of the model, I calibrate the model and solve it numerically. Simulations show that the model can match the high returns on commodity currencies and the fact that most of this return comes from high real interest rates. The model is also consistent with low short-run forecastability of real exchange rates, the volatility of the real exchange rate, and the relatively high elasticity of exchange rates to commodity price movements in commodity countries. The model does not rely on counterfactually large movements in labor costs.

Still, because the model uses certain standard assumptions, it inherits some well-known limitations. For example, I assume financial markets are complete, so households share risk perfectly. While complete markets is a common assumption, it leads to what is known as the Backus-Smith (1993) puzzle. Assuming a standard

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1I follow Barro (2006), Barro and Ursúa (2008), Barro and Ursúa (2012), Barro, Nakamura, Steinson, and Ursúa (2013), and use their consumption data where applicable.
consumer utility function, a country should be assigned more consumption during times when its consumption is relatively cheap, but we do not observe such a correlation. A recent literature suggests that this puzzle can be resolved with more sophisticated forms for household preferences that allow the marginal utility of consumption to depend additional factors beyond the level of contemporaneous consumption.\textsuperscript{2}

In the final section of the paper, I build a New Keynesian extension of the model in which nominal wages are sticky and labor costs may not adjust frictionlessly as a result.\textsuperscript{3} Instead, households have infrequent, randomly arriving opportunities to reset the wage they demand. I find that, assuming the central bank adopts a floating exchange rate and targets a zero output gap, nominal wage stickiness does not hinder the adjustment of real relative labor costs. Even if labor costs are fixed in their own currencies, the nominal exchange rate can move flexibly to adjust relative costs. A central bank defending a currency peg, however, will not be able to adjust labor costs so quickly, and will experience output booms when commodity prices are high, and busts when commodity prices are low. The risk premium on the real exchange rate is, naturally, lower in the case of the peg, since the real exchange rate simply moves much less.

My explanation for high commodity currency returns complements the one provided by Ready, Roussanov, and Ward (2013). Like me, they argue that real exchange rates in commodity countries are cyclical, and thus get a risk premium. In their model, however, the cyclicity comes from shipping costs. Commodity exporters need to import consumer goods from abroad, and their cost of living rises during good times because shipping costs tend to be higher. My paper supplies an alternative reason why the cost of living would rise in booming commodity exporters: higher labor costs.

The present paper is also related to Farhi and Gabaix (2015) in that both papers


\textsuperscript{3}Obstfeld and Rogoff (1995) and Gali and Monacelli (2005) develop textbook sticky-price models of the open economy, and Erceg, Henderson, and Levin (2000) develop the approach to wage stickiness I adopt in this paper.
express real exchange rates as a function of export productivity, and both papers take a rare disasters approach to asset pricing. In that paper, many countries all export the same tradable good, potentially with different levels of productivity. Since my paper focuses on commodities, I explicitly make commodities and finished goods different, by making commodities a non-consumable input good. This setup provides a simple mechanism for commodity prices to be cyclical, as input prices rise during times of high world productivity. Additionally, I focus on labor costs specifically, while Farhi and Gabaix take a more general approach of having tradable and non-tradable industries split a stochastic endowment.

This paper also links with the extensive literature on carry trades and the forward premium puzzle. Carry trades are trading strategies that go long currencies with high interest rates and short currencies with low interest rates. Carry trades make money in two ways: fixed bets on currencies that have permanently (or at least, persistently) high interest rates, and time-varying bets on currencies based on their current interest rate being higher or lower than average. Commodity currencies fall in the former category of currencies with persistently high interest rates, while the “forward premium puzzle” refers to the latter way of making money. Ready, Roussanov, and Ward (2013) find that their “commodity trade” explains about half the variation in monthly returns on an unconditional carry trade that only makes fixed bets on high-interest-rate countries.

In terms of other literature, I build on the existing work on commodity currencies (Chen and Rogoff 2003; Cashin, Céspedes, and Sahay 2004; Clements and Fry 2008; Kearns 2007; Tokarick 2008) and I also contribute to the growing literature on country-specific currency risk premia. Several other variables have been identified that seem correlated with risk premia, including country size (Hassan 2013), country “systemic”-ness (Hassan, Mertens, and Zhang 2015), trade network centrality (Richmond 2015), monetary policy (Backus, Telmer, Gavazzoni, and Zin 2013; Chinn and Zhang 2015), financial imbalances (Della Corte, Riddiough, and Sarno 2015); and status as a world reserve asset (Rey 2013; Maggiori 2012, 2013; 2015).  


5Hassan and Mano (2015) provide details on the differences between, and returns on, the two types of strategies. See Fama (1984) for early empirical findings on the forward premium puzzle. A number of explanations have been suggested for the forward premium puzzle, including expectations errors (Froot and Frankel 1989), habit formation preferences (Verdelhan 2010), variable rare disasters (Gabaix 2012, Farhi and Gabaix 2015), long-run risks (Colacito and Croce 2011, 2013), partially segmented financial markets (Gabaix and Maggiori 2015), and infrequent portfolio decisions (Bachetta and van Wincoop, 2010).
Mueller, Porchia, and Vedolin 2014; He, Krishnamurthy, and Milbradt 2015).

I also connect with recent work measuring commodity risk premia. A num-
ber of papers find significant excess returns to commodity portfolios (Gorton and
Rouwenhorst 2006; Gorton, Hayashi, and Rouwenhorst 2013; Yang 2013; Bhard-
waj, Gorton, and Rouwenhorst 2015). Dhume (2010) suggests a consumption-
based explanation for these commodity premia, and Lettau, Maggiori, and Weber
(2014) price both commodities and currencies using a downside-risk CAPM.

2 Model

2.1 Setup

Time is discrete and indexed by integers $t$, where $t \geq 0$. At each time $t$, there
are different possible states; the state at time 0 is $s_0$, at time 1 $s_1$, etc. A history
$s^t = (s_0, s_1, \ldots, s_t) \in S^t$ is a tuple of states from the beginning of the model to date
$t$. $\mathcal{P}(s^t)$ is the probability of reaching history $s^t$ conditional on information at time
zero.

There are two countries: Australia and the United States. At history $s^t$, Aus-
tralia produces $Y^*_C(s^t)$ units of a non-consumable commodity and $Y^*_{NT}(s^t)$ units
of a non-tradable good. The US produces $Y^*_F(s^t)$ units of a finished good, which
uses the commodity as an input, and $Y^*_{NT}(s^t)$ units of its own non-tradable good.

 Tradable goods are traded frictionlessly, while non-tradable goods can only be
consumed locally.

Australia

Markets are complete, so we can think of the Australian household as simply per-
forming a time-0, “static” optimization in which consumption at each history $s^t$
(for all $t$) is a different good.

Assuming time-separable power utility, the household maximizes:

$$U^* \equiv \sum_t \sum_{s^t \in S^t} \mathcal{P}(s^t) \beta^t \left( \frac{C^*(s^t)^{1-\gamma}}{1-\gamma} \right)$$

where $\beta$ is the household’s subjective discount factor and $C^*(s^t)$ is a Cobb-Douglas
consumption index. This index aggregates finished good consumption, $C^*_F(s^t)$
and non-tradable consumption \( C_{NT}^* (s^t) \):

\[
C^* (s^t) \equiv \kappa C_F^* (s^t)^\chi C_{NT}^* (s^t)^{1-\chi}
\]

In these equations, \( \gamma \) is the coefficient of relative risk aversion, \( \chi \) is the finished good share of nominal consumption, and \( \kappa \) is a normalizing factor equal to \( \chi^{-\chi} (1 - \chi)^{-(1-\chi)} \).

The household is endowed with a single unit of labor, implying that

\[
L_C^* (s^t) + L_{NT}^* (s^t) = 1
\]

for all \( s^t \). The two variables on the left-hand side are labor used producing commodities and labor used producing the non-tradable good.

The household’s budget constraint, measured in units of the time-0 consumption basket, is:

\[
A^* + \sum_t \sum_{s^t \in S^t} \psi^* (s^t) W^* (s^t) = \sum_t \sum_{s^t \in S^t} \psi^* (s^t) C^* (s^t)
\]

In this equation, \( A^* \) is net initial claims that Australia has on the US; \( W^* (s^t) \) is the wage at history \( s^t \), measured in units of consumption at that history; and \( \psi^* (s^t) \) is the price, in terms of time-0 consumption, of an Arrow-Debreu security paying 1 unit of consumption at history \( s^t \).

In this constrained maximization, the household’s control variables are the consumption and labor functions: \( C_F^* (s^t) \), \( C_{NT}^* (s^t) \), \( L_C^* (s^t) \), and \( L_{NT}^* (s^t) \).

In Australia, representative firms, acting in competitive markets, produce both goods using labor as the only input. Firms maximize profits. For simplicity, output is linear in labor:

\[
Y_C^* (s^t) = Z^* (s^t) L_C^* (s^t) \\
Y_{NT}^* (s^t) = Z^* (s^t) L_{NT}^* (s^t)
\]

where \( Z^* (s^t) \) is an exogenous productivity process for Australia.

**The labor cost mechanism**

We can already see how labor cost disease links commodity prices and real exchange rates. Profit maximization implies that, for each firm, the marginal benefit of producing one more unit of output equals the marginal cost of hiring some-
one for $1/Z^*$ hours. In particular, for the commodity sector and the non-tradable sector:

$$P^*_C (s^t) = W^* (s^t) / Z^* (s^t) \quad (1)$$

$$P^*_{NT} (s^t) = W^* (s^t) / Z^* (s^t) \quad (2)$$

where $P^*_C (s^t)$ and $P^*_{NT} (s^t)$ are the prices of the commodity and the Australian non-tradable good, measured in units of the contemporaneous consumption basket.

Anything that increases commodity prices must increase non-tradable prices, because they both depend on the same labor input. The rise in non-tradable prices will raise the real exchange rate, since tradable goods have the same real price in both countries.

Given that commodity prices and real exchange rates are correlated, we still need commodities to have a risk premium in order for commodity currencies to get one, too. I build a simple microfoundation for the risk premium on commodity prices, based on demand for commodities being cyclical. However, any stochastic discount factor that gives a risk premium to commodities (which is, in fact, observed; see Figure 3) should also give a similar risk premium to commodity currencies.

**United States**

The United States household faces a similar problem to the Australian household. It maximizes

$$U = \sum_{t} \sum_{s^t \in S^t} \mathcal{P} (s^t) \beta^t \left( \frac{C (s^t)^{1-\gamma}}{1 - \gamma} \right)$$

where the aggregate consumption index is now:

$$C (s^t) \equiv \kappa C_F (s^t)^{\chi} C_{NT} (s^t)^{1-\chi}$$

The US household is also endowed with a single unit of labor, implying that

$$L_F (s^t) + L_{NT} (s^t) = 1$$

for all $s^t$. The two variables on the left-hand side are labor used producing the finished good and labor used producing the non-tradable good.
The household’s budget constraint, measured in units of its time-0 consumption basket, is:

\[ A + \sum_t \sum_{s^t \in S^t} \psi(s^t) W(s^t) = \sum_t \sum_{s^t \in S^t} \psi(s^t) C(s^t) \]

where \( A \) is net initial claims on Australia, \( W(s^t) \) is the wage in terms of consumption at history \( s^t \), and \( \psi(s^t) \) is the price for a consumption claim paid at history \( s^t \).

In the US, production of the finished good uses a Cobb-Douglas technology with two inputs: labor, with share \( \alpha \), and the commodity, with share \( 1 - \alpha \). Commodity input equals total commodity output, since there is only one use of the commodity. Non-tradables are produced with a simple linear production function.

\[ Y_F(s^t) = Z(s^t) L_F(s^t)^{\alpha} Y^*_C(s^t)^{1-\alpha} \]
\[ Y_{NT}(s^t) = Z(s^t) L_{NT}(s^t) \]

To see directly why commodity prices are cyclical, take the finished good producer’s first-order condition with respect to commodity input:

\[ \underbrace{P_C(s^t)}_{\text{marginal cost}} = \underbrace{P_F(s^t)}_{\text{marginal benefit}} (1 - \alpha) Z(s^t) L_F(s^t)^{\alpha} Y^*_C(s^t)^{-\alpha} \]  

where \( P_C(s^t) \) is the commodity price, and \( P_F(s^t) \) is the finished good price, both relative to the contemporaneous US consumption basket. All else equal, an increase in US productivity \( Z \) raises commodity prices \( P_C \), making commodity prices cyclical so long as these demand shocks have a larger impact on commodity prices than any Australian supply shocks. Of course, commodity prices and productivity will not be exactly proportional, since, in equilibrium, \( L_F \) and \( Y^*_C \) will be determined by the value of \( Z \) as well. It can be shown that exact proportionality holds in the case of log utility (\( \gamma \to 1 \)).

**Specifying the shocks**

There are two exogenous processes for productivity, \( Z(s^t) \) and \( Z^*(s^t) \). Since we are interested in risk premia rather than absolute rates of return, I abstract from
trend growth, so productivity is stationary around a steady state in both countries.\footnote{The nominal exchange rate can still be nonstationary. For example, productivity, and by extension, every real variable in the model, could be constant, but price levels in each country could be random walks that are not cointegrated. Lustig, Stathopoulos, and Verdelhan (2015) discuss the stationarity of nominal exchange rates.}

Productivity in Australia follows an AR(1) in logs. I use lowercase letters to denote logs of uppercase letters:

\[
z^*_t = az^*_{t-1} + u_t
\]

where \( u_t \sim N\left(0, \sigma^2_u\right) \).

Productivity in the US also has an AR(1) structure, but with rare disasters:

\[
z_t = az_{t-1} + v_t
\]

The shock \( v_t \) has distribution:

\[
v_t = \begin{cases} 
    h_t & \text{w.p. } 1 - d_p \\
    h_t + b & \text{w.p. } d_p
\end{cases}
\]

where \( h_t \sim N\left(0, \sigma^2_h\right) \), \( B < 1 \) is the factor by which productivity is multiplied when there is a disaster, and \( d_p \) is the probability of a disaster, which is constant. I assume that \( h_t \) and \( u_t \) are drawn from a multivariate normal distribution with correlation \( \rho_{uh} \).

**The real exchange rate**

The real exchange rate \( Q\left(s^t\right) \) is the price of one unit of consumption in Australia, measured in units of US consumption. The real exchange rate is determined by the relative price of non-tradable goods, because if consumption was entirely of tradable goods, any differences in the cost of living could be arbitraged away.

To see the real exchange rate in terms of nontradables, we need to do a bit of algebra. First, we make use of the fact that, with a homothetic consumption aggregator, if prices are measured in terms of the consumption good, then the total cost of consumption equals the quantity consumed:

\[
P_F\left(s^t\right) C_F\left(s^t\right) + P_{NT}\left(s^t\right) C_{NT}\left(s^t\right) = C\left(s^t\right)
\]
both sides can be divided by $C \left( s^t \right)$ to yield:

$$P_F \left( s^t \right)^\chi P_{NT} \left( s^t \right)^{1-\chi} = 1$$

Similarly, in Australia,

$$P^*_F \left( s^t \right)^\chi P^*_{NT} \left( s^t \right)^{1-\chi} = 1$$

A single unit of Australian consumption can be sold for $1/P^*_F \left( s^t \right)$ units of the finished good (a higher price for the finished good means a lower quantity of units purchased). These units can then be exported to the US and sold at a price $P_F \left( s^t \right)$ per unit, measured in the US consumption good. Thus, the real exchange rate is

$$Q \left( s^t \right) = \frac{P_F \left( s^t \right)}{P^*_F \left( s^t \right)}$$

Using this fact, and plugging in our Cobb-Douglas identities, the equation for the real exchange rate simplifies to:

$$q \left( s^t \right) = \left( \frac{1-\chi}{\chi} \right) \left( p^*_{NT} \left( s^t \right) - p_{NT} \left( s^t \right) \right)$$

where lowercase letters denote natural logs.

This formula simply reflects the intuition that higher non-tradable prices in Australia require a higher equilibrium real exchange rate.

### 2.2 Solving the model

**Equilibrium**

The model uses a standard definition of competitive equilibrium.

1. Households maximize utility subject to their budget constraints. Formally, the control variables $C_F \left( s^t \right)$, $C_{NT} \left( s^t \right)$, $C^*_F \left( s^t \right)$, $C^*_{NT} \left( s^t \right)$, $L_F \left( s^t \right)$, $L_{NT} \left( s^t \right)$, $L^*_C \left( s^t \right)$, and $L^*_NT \left( s^t \right)$ must solve the household maximization problems.

2. Second, firms maximize profits. The firm’s choice variables are $L_F \left( s^t \right)$, $L_{NT} \left( s^t \right)$, $L^*_C \left( s^t \right)$, and $L^*_NT \left( s^t \right)$.

3. Finally, goods markets clear. Since we are using the Arrow-Debreu formulation, this is equivalent to financial market clearing, as the financial assets are
equivalent to goods at different histories. Formally, this means
\[ C_F(s^t) + C^*_F(s^t) = Y_F(s^t) \]
\[ C_{NT}(s^t) = Y_{NT}(s^t) \]
\[ C^*_N(s^t) = Y^*_N(s^t) \]
for all histories \( s^t \).

Social planning formulation

We simplify the problem by taking a “social planning” approach. Because markets are complete, the competitive equilibrium is Pareto optimal. Consequently, the equilibrium quantities can be written as the solutions to a social planner’s dynamic control problem:

\[
\max \sum_t \sum_{s^t \in S^t} \beta^t \left[ v \left( \frac{C(s^t)^{1-\gamma}}{1-\gamma} \right) + (1-v) \left( \frac{C^*(s^t)^{1-\gamma}}{1-\gamma} \right) \right]
\]

where the control variables are \( C_F(s^t), C_{NT}(s^t), C^*_F(s^t), C^*_N(s^t), L_F(s^t), L_{NT}(s^t), L^*_C(s^t), \) and \( L^*_N(s^t) \). The constraints include both identities and resource constraints. The identities are:

\[ C(s^t) = \kappa C_F(s^t)^\chi C_{NT}(s^t)^{1-\chi} \]
\[ C^*(s^t) = \kappa C^*_F(s^t)^\chi C^*_{NT}(s^t)^{1-\chi} \]

The resource constraints are:

\[ C_F(s^t) + C^*_F(s^t) = Z(s^t) L_F(s^t)^\alpha (Z^*(s^t) L^*_C(s^t))^{1-\alpha} \]
\[ C_{NT}(s^t) = Z(s^t) L_{NT}(s^t) \]
\[ C^*_N(s^t) = Z^*(s^t) L^*_N(s^t) \]
\[ L_F(s^t) + L_{NT}(s^t) = 1 \]
\[ L^*_C(s^t) + L^*_N(s^t) = 1 \]

Because there are no endogenous state variables and the objective function is linear by state, this problem can be solved independently for each \( s^t \). That simpli-
fied static, deterministic problem is as follows (after substituting in constraints):

$$
\max_{C_F, L_F, L_C^*} \nu \left( \frac{C_F^\chi (Z (1 - L_F))^{1-\chi}}{1 - \gamma} \right) \\
+ (1 - \nu) \left( \frac{(ZL_F^\alpha (Z^* L_C^*)^{1-\alpha} - C_F)^\chi (Z^* (1 - L_C^*))^{1-\chi}}{1 - \gamma} \right)
$$

where the variables are now scalars, solved for the state indexed by \((Z, Z^*)\).

Once this simplified problem has been solved for a particular history \(s^t\), the other quantities can be backed out using the constraints on the dynamic social planning problem. For consumption goods, prices can be computed as ratios of marginal utilities. For the commodity, the price is computed using the firm first-order condition

$$
P_C = (1 - \alpha) P_F ZL_F^\alpha Y_*^{1-\alpha}
$$

where the other terms have already been solved for.

**Numerical solution method**

We know that the competitive equilibrium is Pareto optimal, but we do not know the Pareto weights \(\nu\) and \(1 - \nu\). I compute these numerically using the approach of Negishi (1960), as described in Ljungqvist and Sargent (2000). One makes an initial guess, \(\nu_0\), and then checks the budget constraints. One then iterates this process, guessing \(\nu_{k+1} < \nu_k\) if the present value of US consumption exceeds the present value of US income. I assume \(A = A^* = 0\) in these solutions. The state prices in the budget constraint are computed as the ratio of marginal utilities at history \(s^t\) and history \(s^0\):

$$
\psi (s^t) = \mathcal{P} (s^t) \beta^t \left( \frac{C (s^t)}{C (s^0)} \right)^{-\gamma}
$$

**2.3 Accounting for non-commodity exports**

As written, the model forces the commodity country to be a 100% commodity exporter. In reality, even for a country like Australia, commodities make up only about half of exports (although this figure varies over time). Accounting for this
difference is not important for the main conclusions of the model, but it will be important quantitatively when we turn to calibration, since otherwise we will predict effects that are too strong.

To capture alternative exports, I take a reduced-form approach. I introduce an alternative export good \( A \) in Australia. Output of this good, like the commodity, is linear in labor:

\[
Y^*_A (s^t) = Z^* (s^t) L^*_A (s^t)
\]

To make this sector bigger or smaller, we simply embed a bigger or smaller preference \( \phi \) for consuming this good in the US:

\[
C (s^t) = \kappa_{US} C_F (s^t)^\chi C_A (s^t)^\phi C_{NT} (s^t)^{1-\chi-\phi}
\]

where \( \kappa_{US} \equiv \chi^{-\chi}\phi^{-\phi} (1 - \chi - \phi)^{-(1-\chi-\phi)} \).

Since the good is not consumed in Australia, market clearing implies:

\[
C_A (s^t) = Z^* (s^t) L^*_A (s^t)
\]

so the only new endogenous variable is \( L^*_A (s^t) \).

The final, state-specific social planning problem simply becomes:

\[
\max_{C_F, L_F, L^*_C, L^*_A} \nu \left( \frac{C_F^\chi (Z (1 - L_F))^{1-\chi}}{1 - \gamma} \right) + (1 - \nu) \left( \frac{(Z L^*_C (Z^* L^*_A)^{1-\chi} - C_F)^\chi (Z^* L^*_A)^\phi (Z^* (1 - L^*_C - L^*_A))^{1-\chi}}{1 - \gamma} \right)
\]

The taste parameters \( \chi \) and \( \phi \) can then be calibrated to match data on the commodity sector share of exports and the export share of GDP.

## 3 Empirics

This section describes how I empirically evaluate the model. First, I make estimates of the key economic mechanisms. This task includes using panel data, merged with currency and commodity data, to measure how much exchange rates, commodity prices, and real wages are moving. Second, I do a quantitative calibration exercise to see if the model can match economic variables for the Australia-US
country pair.

In Appendix C, I fully describe the data sources and construction of individual time series. For the body of the paper, I simply provide short descriptions as I introduce each new series.

3.1 Key Estimates

3.1.1 Currency-commodity elasticities and correlations

In my model, commodities are cyclical, and their risk premium is inherited by commodity currencies through the labor cost mechanism. Thus two things need to be true in the data: first, commodity currencies are highly correlated with commodity prices; second, commodity currencies are highly elastic to commodity prices. (To expand on the latter point, it is difficult to get a big risk premium on something that doesn’t move very much, even if it is cyclical.)

Figure 2 plots exchange rates alongside commodity export prices for a variety of commodity exporters. One can immediately see that they are quite correlated. The commodity price index is export-weighted and specific to each country.

To compute this commodity price index, I use data from the Commodity Research Bureau (CRB); one can purchase a CD with daily data on the entire futures curve for a comprehensive set of futures traded on many exchanges. The details of how spot prices, returns, and commodity basis are calculated from these data are provided in Appendix C.

I estimate both short-run and long-run elasticities. Short-run elasticities measure the quarterly change in the real exchange rate associated with a contemporaneous quarterly change in commodity prices. The baseline time-series regression to estimate a short-run elasticity is therefore:

\[ \Delta q_t^j = \beta^j \Delta \text{cmpi}_t^j + \alpha^j + \varepsilon_t^j \]

where \( q_t^j \) is the log real exchange rate for country \( j \) against the U.S. dollar, and \( \text{cmpi}_t^j \) is the real export-weighted commodity price index. The commodity price index is “real” in the sense that it is a U.S. dollar nominal quantity deflated by the U.S. CPI. Short-run regressions can be interpreted as measuring the substitutability

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7 See equations (1)-(3) for details and discussion.
8 Figure 2 uses nominal variables; graphs with real exchange rates can be found in Appendix C, Figures 9, 10, and 11, but are at a lower (quarterly) frequency.
between currency and commodity investment positions from the perspective of a short-horizon investor. The regression results are reported in Table 3.

Because changes in commodity prices sometimes have a delayed effect on real exchange rates, to avoid bias in the contemporaneous coefficient, we can include a lag of the right-hand variable in the regression. These alternative estimates are given in Table 4, and I find that they are slightly better correlated with a measure of commodity exports (CMXPTR) than the baseline estimates (correlations are 0.55 versus 0.47).

Long-run elasticities measure the long-run effect of a commodity price change on the real exchange rate. A long-run elasticity can be interpreted as measuring the degree of substitutability between currency and commodity investments for a long-term investor. The long-run effect may be larger than the short-run effect because commodity price changes could have a delayed effect on the real exchange rate. Additionally, at short (quarterly) horizons, much of the variation in real exchange rates is not related to commodity prices, even for commodity currencies; at longer horizons, this transient noise becomes less important.

The previous literature on commodity currencies has mostly focused on measuring long-run elasticities (see, for example, Chen and Rogoff 2003, and Céspedes, Cashin, and Sahay 2004). Following the literature, I estimate long-run elasticities by regressing the log real exchange rate on the log commodity price index:

\[ q_i^t = \beta_i^t \text{cmpp}_i^t + \alpha_i^t + \epsilon_i^t \]

The specification of the regression in levels, rather than differences, is consistent with the assumption of cointegration between the two variables, which is usually maintained in the literature. The idea is that a levels specification picks up delayed effects of commodity prices on exchange rates. This approach would be problematic if both processes did have a unit root but were not cointegrated, but that does not seem consistent with Figure 2. The results of these regressions are displayed in Table 5.

Although using long-run elasticities is consistent with previous work, significant caution is required when interpreting them. As Céspedes, Cashin, and Sahay (2004) show, there are a number of cases in which the relationship between the real exchange rate and commodity prices “regime shifts” to a new level. Failing to control for that shift, which is not always in the form of an discrete jump, may bias the estimate of \( \beta_i^t \) relative to a reasonable value for \( \beta_i^t \) assuming that such a
shift will not occur in the future. Rather than try to identify these shifts — which involves some subjective judgment — I will only use these long-run elasticities for cases such as Australia in which there are no obvious jumps and there have been no major changes in monetary policy in recent history.

The general conclusion of all three tables of regressions is that commodity prices do have significant effects on commodity currencies, both in the short and long run.

### 3.1.2 Currency risk premia and commodity risk premia

If commodities themselves are not particularly cyclical, or not have much of a risk premium, then it is impossible for commodity currencies to inherit that risk premium. Fortunately, a recent literature (Gorton and Rouwenhorst 2006; Gorton, Hayashi, and Rouwenhorst 2013; Yang 2013; Bhardwaj, Gorton, and Rouwenhorst 2015) finds significant excess returns to commodities, and higher returns on more cyclical commodities (Dhume 2010). I confirm high excess returns in Figure 3 of this paper, which is based on data from CRB.\(^9\)

Indeed, not only should commodities have a risk premium, but it is important that currency risk premia be consistent with commodity risk premia. For example, a currency should not have an expected excess return of 10%, if the commodities it exports have an expected excess return of 1%, and the currency-commodity elasticity is only 0.5. (That said, we need not expect a perfect relationship, because, as we saw in Tables 3 and 4, even countries like Australia have most of their short-run currency risk coming from factors besides commodities.)

Before we can estimate the relationship between currency and commodity risk premia, however, we need a measure of commodity expected returns; I use the commodity basis. Many commodities are traded on futures exchanges, and the futures price being higher or lower than the current spot market price creates a natural return that would be earned in the absence of any changes in commodity prices. This “carry” on a long commodity position is called the commodity basis; Figure 3 shows that it is highly correlated with realized commodity returns. Appendix C gives details on how basis is computed for each commodity; it is expressed as an annualized percentage.

Although basis can predict commodity returns, it is a somewhat negatively biased predictor. This bias may be due to commodity storage costs, which imply

\(^9\)Lettau, Maggiori, and Weber (2014) use a downside-risk CAPM to price both commodities and currencies.
returns have to be slightly higher for the short party (the promising to deliver the commodity). I unbias the basis values by simply adding the intercept term from a cross-sectional regression of commodity returns on basis values.

We also need estimates of commodity expected returns at the national level, not at the commodity level. I construct export-weighted basis values for each country. These are not time series indexes; they are just one value of each country, based on time-series-average export weights and time-series-average basis values for each commodity. The reason for not creating time series is that some (quite important) commodities, such as iron and coal, do not start being traded on futures exchanges until relatively recently; thus, any countries exporting these commodities would have inaccurate measures of commodity risk before those dates.\(^{10}\)

To estimate the relationship between currency risk premia and commodity risk premia, I estimate the four cross-sectional regressions. In each case, I regress a proxy for expected returns on currencies on a proxy for expected returns on commodities, scaled by the currency’s exposure to commodity risk. The differences between the cases lie in the different proxies used for each term.

Specifically, I estimate the following four models, with results shown in Table 6:

1. \[rxh^j = \beta \left( \hat{\eta}^j \cdot \text{cmbasis}^j \right) + \alpha^j + \epsilon^j\]
2. \[r^j - r = \beta \left( \hat{\eta}^j \cdot \text{cmbasis}^j \right) + \alpha^j + \epsilon^j\]
3. \[rxh^j = \beta \left( \text{CMXPTR}^j \cdot \text{cmbasis}^j \right) + \alpha^j + \epsilon^j\]
4. \[r^j - r = \beta \left( \text{CMXPTR}^j \cdot \text{cmbasis}^j \right) + \alpha^j + \epsilon^j\]

For the left-hand side variable, in regressions (1) and (3), the expected real excess return on each currency is proxied by \(rxh^j\), the time series average. In regressions (2) and (4), the average real interest rate differential \(r^j - r\) (real carry) is used instead. For the right-hand side variable, in all regressions (1)-(4), the export-weighted average basis is used as a proxy for commodity expected returns. In equations (1) and (2), the average basis is scaled by the estimated currency-commodity elasticity \(\hat{\eta}^j\) from Table 4. As a robustness check, equations (3) and (4)

---

\(^{10}\)This point is related to the interesting result of Kearns (2007). He finds that the risk premium on the Australian dollar is much higher than the risk premium on the commodities exported by Australia. While we use different data sources, one possible reason for the difference in results is that, because his paper was written originally around 2001, his commodity dataset ends in 2000, before the introduction of futures contracts on coal and iron ore (in late 2001 and 2013, respectively). These are Australia’s two biggest commodity exports, and they both have large basis values in my dataset. I get results similar to his if I exclude these commodities.
simply use CMXPTR$^j$, a measure of commodity exports, in place of the estimated currency-commodity elasticity.

Ideally, we would observe a $\beta$ of near one in regressions (1) and (2), implying that currency and commodity returns are roughly consistent. Indeed, we find estimates of 0.60 and 0.78, both of which are not significantly different from 1, but are significantly different from zero. (The coefficients estimated in regressions 3 and 4 are not particularly interpretable, because CMXPTR is normalized to be between -1 and 1.) Moreover, across the four models, about a quarter of the cross-sectional variation in average currency returns can be explained by these commodity factors.

### 3.1.3 Labor costs

The main mechanism of my model is labor cost disease. Formally, this is an increase in relative unit labor costs. Unit labor costs are labor compensation divided by labor productivity; in my model, compensation rises in the non-tradable sector to make it competitive with the commodity sector, but productivity does not rise, leading to an increase in unit labor costs (compared to the commodity country).

Quarterly unit labor cost data are available from the OECD, and these can be adjusted for inflation and purchasing power parity so that they are comparable across time and countries. A key limitation of this data is that not all OECD countries are included, and, ultimately, only four of the remainder are truly commodity exporters: Australia, New Zealand, Canada, and Norway. Nevertheless, time series regressions in each of these countries supports the idea that labor costs move contemporaneously with commodity prices.

I regress 4-quarter growth in log real unit labor costs, relative to the United States, from four OECD commodity exporters (Australia, New Zealand, Canada, and Norway) on 4-quarter growth in log real commodity prices. The equation to be estimated is for each country $j$ is:

$$\Delta \ln \left( \text{relative unit labor costs}_t^j \right) = \beta \Delta \ln \left( \text{export cmdty prices}_t^j \right) + \alpha^j + \epsilon_t^j$$

Commodity prices are country-specific, export-weighted indices computed from CRB futures data. I use Newey-West standard errors to adjust for overlapping observations. The results are shown in Table 7.

Broadly speaking, we see unit labor cost elasticities of between 0.1% to 0.5% for every 1% increase in commodity prices, and these estimates are statistically
significant in all four countries.

Since these changes in labor costs could simply reflect short-run factors, I also do long-run regressions in levels, in the spirit of the regressions run in Table 5. These regressions follow the specification

\[
\ln \left( \text{relative unit labor costs}_t^j \right) = \beta \ln \left( \text{export cmdty prices}_t^j \right) + \alpha^j + \epsilon^j_t
\]

Table 8 displays the results, which are stronger than those run in differences, with the exception that, for New Zealand, the \(R^2\) value is lower for the levels regression than for the differences regression.

Since the OECD data are limited, I augment this analysis with a comparison of oil-exporting US states and non-oil exporting US states. An advantage of this approach is that labor cost data are collected using uniform procedures. We will only be able to study nominal wage data because CPI data are not computed on a state-by-state basis.

In recent years, hydraulic fracturing technology has transformed the U.S. into a significant oil producer. During this period, there were two instances of sharp drops in oil prices: once during the financial crisis, and once toward the end of 2014. If labor costs can be driven by commodity prices, we should observe simultaneous falls in labor costs in oil-producing states, relative to non-oil-producing states.

Assuming non-oil-producing states to be a valid control group is a conservative assumption, because people can move across state borders — particularly, to help a growing sector expand — and thus interstate labor cost differences will be less pronounced than international labor cost differences.

I take my set of oil-producing states from a report by Deutsche Bank on shale oil (Ferro 2015). The set of oil-producing states is: Texas, North Dakota, Oklahoma, Louisiana, Pennsylvania, Wyoming, New Mexico, Colorado, Arkansas, Utah, Kansas, and West Virginia, as shown in Figure 8 (in the Appendix).

Figure 4 shows that growth in nominal crude oil prices are highly correlated with growth in oil-state nominal wages.

I regress the trailing-12-month change in log nominal wages (in oil states relative to non-oil states) on the 12-month change in log dollar oil prices. The specification is:

\[
\Delta \ln \left( \frac{\text{oil-state wage}_t}{\text{non-oil state wage}_t} \right) = \beta \Delta \ln (\text{WTI Crude Price}_t) + \alpha + \epsilon_t
\]
This estimate yields an $R^2$ of 0.32 and a Newey-West $t$-statistic of 4.5; details are reported in Table 9.

Finally, one might worry that labor markets are segmented; an increase in labor compensation in the tradable sector might not have much of an effect in the non-tradable sector, because labor is not perfectly, or rapidly, substitutable between sectors. While I do not explore this possibility in depth, I conduct a very simple consistency check with quarterly OECD nominal wage data. (Nominal wages are the appropriate measure, because they need to be the same across sectors to make the marginal worker indifferent.) I regress changes in log non-tradable wages on log tradable wages, using a panel of 30 OECD countries:

$$\Delta \ln \left( \text{nontradable_wage}_t^j \right) = \beta \ln \left( \Delta \text{tradable_wage}_t^j \right) + \nu_t^j + \mu_t + \epsilon_t^j$$

A 4-quarter increase in tradable wages of 1% is associated with with a 0.8% increase during the same period in non-tradable wages. This finding suggests that the two markets have wage movements that are, at least, fairly correlated. The regression results are reported in Table 6.

3.2 Calibration

In this section, I show the results from calibrating the model’s parameters to standard values for the Australia-US pair. I run simulations based on these values and compare the theoretical moments generated by the simulation to actual means, variances, and covariances in the data. Overall, the model provides a decent fit to the data, although it cannot account for certain features, such as the Backus-Smith (1993) puzzle.

3.2.1 Parameter choices

Table 1 shows the calibrated parameter choices, which I explain in the following.

The first set of parameters is calibrated to basic facts about the economy: I take a risk aversion of $\gamma = 4$ and annual discount factor $\beta = 0.97$ from Barro (2006). I use a labor share $\alpha$ of 70% to match US data, and I calibrate $\chi = 0.14$ and $\phi = 0.06$ to match two key pieces of data: Australian commodity exports as a share of total exports (52%) and Australian exports as a fraction of GDP (20%); these data points are averages between 1995 and 2014.

The second set of parameters governs the stochastic processes in the model,
namely, productivity in the US and in Australia. These are calibrated to match the consumption data from Barro (2006) and Barro and Ursúa (2013). Specifically, I take the probability of a disaster \( p = 1.7\% \) and the average loss in consumption conditional on disaster (29%, implying \( B = 0.71 \)) from Barro (2006). I then compute consumption growth in both countries using the Barro and Ursúa dataset on an annual basis from 1995 - 2009, the end of that dataset. This is a period without disasters for both countries, according to their definition, which puts a lower bound on a disaster of a 10% fall in aggregate consumption. I use these data to calibrate \( \sigma_u, \sigma_h, \text{ and } \rho_{uh} \), which govern productivity shocks in the absence of disasters. I set the productivity persistence parameter \( a \) to 0.87 to provide a 5-year half-life on the real exchange rate, as suggested by the literature on purchasing power parity.

Table 2 shows that the chosen parameters replicate the microeconomic data to which the model is calibrated.

<table>
<thead>
<tr>
<th>Economy</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk aversion ( \gamma )</td>
<td>4</td>
</tr>
<tr>
<td>Labor share ( \alpha )</td>
<td>0.7</td>
</tr>
<tr>
<td>Discount factor ( \beta )</td>
<td>0.97</td>
</tr>
<tr>
<td>Taste for finished goods ( \chi )</td>
<td>0.14</td>
</tr>
<tr>
<td>Taste for the alternative good ( \phi )</td>
<td>0.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shocks</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity AR(1) ( a )</td>
<td>0.87</td>
</tr>
<tr>
<td>Disaster probability ( d_p )</td>
<td>1.7%</td>
</tr>
<tr>
<td>Shock volatility ( \sigma_u )</td>
<td>0.18</td>
</tr>
<tr>
<td>Shock volatility ( \sigma_h )</td>
<td>0.21</td>
</tr>
<tr>
<td>Shock correlation ( \rho_{uh} )</td>
<td>-0.2</td>
</tr>
<tr>
<td>Disaster factor ( B )</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Table 1: Calibration parameters. Most of the choices are directly from Barro (2006), or in the case of the shocks, matched to the consumption data in Barro and Ursúa (2013). The taste parameters are chosen to match Australian export data.
Table 2: Economic statistics used for calibration. The model parameters are determined by certain microeconomic facts, like the volatility of consumption growth and the fall in consumption upon disaster measured in Barro (2006) and Barro and Ursúa (2013). The model replicates these statistics by construction.

### 3.2.2 Key predictions

First, I discuss the unconditional real risk premium on the commodity currency. The risk premium is the sum of two parts: the average real interest rate differential $r^*_t - r_t$, and the average real appreciation of the Australian dollar, $\Delta q_{t+1}$. The data are averages taken over the past 20 years (that is, starting in 1995-Q1), using data sources described in the Appendix. Since the data moments are estimated, 95% confidence intervals around the estimates are also displayed. These means are unconditional means.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Model</th>
<th>Data (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AU Commodity exports / Gross exports</td>
<td>0.51</td>
<td>0.52</td>
</tr>
<tr>
<td>AU Gross exports / GDP</td>
<td>0.22</td>
<td>0.20</td>
</tr>
<tr>
<td>US consumption growth volatility</td>
<td>1.6%</td>
<td>1.6%</td>
</tr>
<tr>
<td>AU consumption growth volatility</td>
<td>1.3%</td>
<td>1.3%</td>
</tr>
<tr>
<td>US-AU consumption growth correlation</td>
<td>0.74</td>
<td>0.73</td>
</tr>
<tr>
<td>Disaster probability</td>
<td>1.7%</td>
<td>1.7%</td>
</tr>
<tr>
<td>Consumption drop on disaster</td>
<td>29%</td>
<td>29%</td>
</tr>
</tbody>
</table>

The model succeeds in matching a large real interest rate spread. The fact that average currency appreciation is zero in the model is actually a strong point: while the Australian dollar has appreciated over the last two decades, the appreciation is not statistically significant, and indeed exchange rate movements seem to be effectively unforecastable in the short run (Rogoff and Stavrakeva 2008).

Turning to the dynamics of the real exchange rate, we find that the model-implied volatility of the real exchange rate during a period of no disasters, 4.6%, is comparable to the observed volatility of the component of the real exchange rate explained by commodity prices, 5.0%. Isolating this component is important
because, as shown in Table 4, there is significant, non-commodity-related variation in the real exchange rate in the short run. It would be strange if the model were able to explain this other variation, too, since the model only has the commodity channel for moving the exchange rate.

<table>
<thead>
<tr>
<th>Moment</th>
<th>Model</th>
<th>Data (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma(\Delta q_t)$</td>
<td>4.6%</td>
<td>5.0% (4.2%, 5.8%)</td>
</tr>
<tr>
<td>$\rho(\Delta q_t, \Delta c_t - \Delta c^*_t)$</td>
<td>1.00</td>
<td>0.34 (-0.23, 0.73)</td>
</tr>
<tr>
<td>$\rho(\Delta q_t, \Delta c_t)$</td>
<td>0.64</td>
<td>0.24 (-0.32, 0.68)</td>
</tr>
<tr>
<td>$\rho(\Delta q_t, \Delta c^*_t)$</td>
<td>-0.04</td>
<td>-0.03 (-0.50, 0.54)</td>
</tr>
</tbody>
</table>

The second row in the above table, also computed for a no-disaster period, shows the Backus-Smith (1993) puzzle. In models with complete markets and standard, time-separable CRRA preferences, an increase in the real exchange rate is only possible through faster growth in US consumption than Australian consumption. Consequently, simulated movements in the real exchange rate are perfectly correlated with the difference in consumption growth rates, while the correlation is much less in the data.

Ideas for fixing the Backus-Smith puzzle in the context of complete markets generally revolve around modifying the household utility function so that the marginal utility of a dollar — which determines the relative value of currency — is determined not only by current consumption, but by additional variables. Colacito and Croce (2011, 2013) suggest a solution for the Backus-Smith puzzle based on the idea of Epstein-Zin preferences and long-run consumption risks. This paper fits into a broader literature on international long-run risks models that includes, among others, Bansal and Shaliastovich (2012), Backus, Telmer, Gavazzoni, and Zin (2013), and Colacito, Croce, Gavazzoni, and Ready (2015). Stathopoulos (2012) takes a habit-formation approach to the Backus-Smith puzzle, in the spirit of Campbell and Cochrane (1999) and Verdelhan (2010).

The third and fourth rows in the above table show correlations between changes in the real exchange rate and consumption growth in each country. The data are not significantly different from either model prediction, although the first correlation is admittedly on the high end. The main surprise here is simply that the model’s exchange rate is not extremely correlated with consumption growth in both countries, since that would help get a high risk premium on the real exchange rate. It turns out that the correlation between the exchange rate and consumption
growth need be high only during disasters, during which everything crashes; the rest of the time, supply shocks can be frequent enough that commodity prices often fall during global growth, which is important for matching the data.

Previously, we estimated two key elasticities: the elasticity of exchange rates to commodity prices, and the elasticity of labor costs to commodity prices. When it comes to the exchange rate elasticity, it is appropriate to compare the model results to the long-run elasticity, since, as discussed previously, the short-run figure does not account for delayed effects of changes in commodity prices that occur instantaneously and frictionlessly in the model. By this standard, the model does fairly well. The unit labor cost elasticity to commodity prices is also close to that observed in the data.

<table>
<thead>
<tr>
<th>Elasticity of...</th>
<th>Model</th>
<th>Data (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta q_{t+1}$ to $\Delta p_{C,t+1}$</td>
<td>0.88</td>
<td>0.96 ± 0.20 (Long-run)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.42 ± 0.22 (Short-run)</td>
</tr>
<tr>
<td>$\Delta rulc_{t+1}$ to $\Delta p_{C,t+1}$</td>
<td>0.82</td>
<td>0.95 ± 0.22 (Long-run)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.40 ± 0.16 (Short-run)</td>
</tr>
</tbody>
</table>

95% confidence intervals are given around the regression estimates. The finding here suggests that we do not need to assume too large movements in labor costs in order to explain the commodity currency puzzle.

4 Monetary model

This section develops a sticky-wage New Keynesian extension for the model we have seen so far, in the style of Erceg, Henderson, and Levin (2000). A monetary model helps us answer three separate questions:

- Real-life currency trades are nominal; they involve nominal interest rates and exchange rates. How does the nominal exchange rate move compared to the real exchange rate?

- Labor costs cannot adjust rapidly through nominal wages if nominal wages are sticky. Instead, the nominal exchange rate (which may be flexible) needs to adjust. Can nominal exchange rates adjust “enough” to replicate the flexible-price allocation?
• Central banks often respond to terms-of-trade shocks by adjusting their nominal exchange rate. With nominal rigidities, the size of this response will affect the covariance between the real exchange rate and commodity prices. What effect does this have on the real currency risk premium?

I study two regimes: floating and fixed nominal exchange rates, the latter of which I refer to as a currency peg. With a floating rate, the central bank tries to replicate the flexible-price allocation.

The main results are as follows. First, under a peg, the nominal exchange rate does not move, so the flexible-price allocation cannot be replicated. The real exchange rate moves less than in the flexible-price allocation, leading to a smaller real exchange rate risk premium. Output gaps are common.

Second, under floating rates, the flexible-price allocation can be replicated, and the results are identical to those in the purely real model considered previously, up to a small distortion from monopolistic competition. The nominal exchange rate moves more than the real exchange rate in order to achieve this outcome.

This model focuses on wage stickiness because labor costs are the main mechanism studied in this paper. The model could be extended, as in Erceg, Henderson, and Levin (2000), to include price stickiness as well, by allowing monopolistic competition between firms. Since I do not use price stickiness, the model also does not directly take a stance on producer- versus consumer-currency pricing, as described in, for example, Betts and Devereux (2000), Devereux and Engel (2003), Gopinath, Itskhoki, and Rigobon (2007), or Gopinath, Gourinchas, Hsieh, and Li (2011).

4.1 Key notational differences

I make the following substitutions relative to the non-monetary model:

• $S_t$ means the nominal exchange rate (defined below).

• $\phi$ means the Frisch elasticity of labor supply.

4.2 Numeraires

In the non-monetary model, all prices were expressed in terms of the consumption bundle; according to this numeraire, the CPI was 1 by definition. Now, all prices are nominal, relative to some notional unit of account (the US or Australian
dollar). The consumer price indexes in the US and Australia are then $P_t$ and $P_t^*$, respectively.

Let $S_t$ be the nominal exchange rate between the USD and the AUD (up implies appreciation of the AUD); this is the rate of substitution between the two different units of account.

Let $Q_t$ be the real exchange rate, or the value of the Australian consumption basket in terms of the US basket:

$$Q_t \equiv \frac{S_t P_t^*}{P_t} \quad (4)$$

The terms of trade $\Theta_t$ is the price of exports in terms of imports (from the point of view of Australia, so it moves in the same direction as the exchange rate):

$$\Theta_t \equiv \frac{P_{C,t}}{P_{F,t}} \quad (5)$$

This relative price was used implicitly in the non-monetary model, but we now give it a symbol to simplify our notation.

### 4.3 Risk Sharing

We continue with the assumption of complete markets. For simplicity, we solve the log utility case, which, given the rest of the setup and no net initial financial claims, implies balanced trade in each period (Cole and Obstfeld 1991). Consequently, neither country accumulates financial claims against the other.

### 4.4 Australia

#### 4.4.1 Australian households

If firms could use the labor of each household interchangeably, it would be difficult for wages to be sticky. Households would have to constantly revise their wages, or else face complete unemployment when their wage happened to be higher than the lowest wage offered on the market. Consequently, we introduce a continuum of households in Australia, indexed by $j$, and the labor of these households will be imperfectly substitutable from the perspective of firms.
Household $j$ has log utility over consumption and power utility in labor hours:

$$U^*_t (j) = E_t \sum_{k=0}^{\infty} \beta^k \left( \ln C^*_{t+k} (j) - \frac{L^*_{t+k} (j)^{1+\phi}}{1+\phi} \right)$$  \hspace{1cm} (6)$$

Because markets are complete domestically, and every household faces the same prices, consumption will be the same for all households. This statement is true even though households may offer different wages and, by extension, face different levels of labor demanded. We denote this common level of consumption $C^*_{t+k}$:

$$C^*_{t+k} (j) = C^*_{t+k} \ \forall \ j$$  \hspace{1cm} (7)$$

As before, for household $j$, consumption is a Cobb-Douglas aggregate of tradable and non-tradable goods:

$$C^*_t (j) \equiv \kappa C^*_{F,t} (j)^\chi C^*_{NT,t} (j)^{1-\chi}$$  \hspace{1cm} (8)$$

where $0 < \chi < 1$ and $C^*_{F,t} (j)$ and $C^*_{NT,t} (j)$ are the consumption levels of the finished and non-tradable goods, and $\kappa \equiv \chi^{-\chi} (1-\chi)^{-(1-\chi)}$ is a normalizing factor. Again, because of complete markets and the homotheticity of the consumption aggregator, the household-level consumption of each good equals aggregate national consumption of that good:

$$C^*_{F,t} (j) = C^*_{F,t} \ \forall \ j$$  \hspace{1cm} (9)$$

$$C^*_{NT,t} (j) = C^*_{NT,t} \ \forall \ j$$  \hspace{1cm} (10)$$

The consumer price index (CPI) based on the optimal consumption bundle is:

$$P^*_t \equiv P^*_{F,t} P^*_{NT,t}^{(1-\chi)}$$  \hspace{1cm} (11)$$

where $P^*_{F,t}$ and $P^*_{NT,t}$ are the prices of the finished and non-tradable goods in Australian dollars.

Household $j$’s budget constraint is:

$$C^*_t (j) P^*_t = W^*_t (j) L^*_t (j) + D^*_t (j)$$  \hspace{1cm} (12)$$

where $W^*_t (j)$ is the nominal wage and $L^*_t (j)$ is labor supply, and $D^*_t (j)$ is the (stochastic) income assigned to household $j$ under the complete-markets alloca-
4.4.2 Australian production

In Australia, there are two sectors of production; in the commodity-exporting sector, \( Y_{C,t}^* \) units are produced, and in the non-tradable sector, \( Y_{NT,t}^* \) units are produced. To follow the non-monetary model as closely as possible, I make total output linear in the “aggregate labor” hired by each firm, but those aggregates are computed with an aggregator function that makes labor from different households imperfect substitutes:

\[
Y_{C,t}^* = \left( \int L_{C,t}^* (j) \frac{\varepsilon - 1}{\varepsilon} dj \right)^{\frac{\varepsilon}{\varepsilon - 1}}
\]  
\( (13) \)

\[
Y_{NT,t}^* = \left( \int L_{NT,t}^* (j) \frac{\varepsilon - 1}{\varepsilon} dj \right)^{\frac{\varepsilon}{\varepsilon - 1}}
\]  
\( (14) \)

where \( L_{C,t}^* (j) \) and \( L_{NT,t}^* (j) \) are the labor supplies from each household \( j \) to the two industries, substituted into the production function. For simplicity, I omit the local supply shock, \( Z^* \), which was in the non-monetary model.

We introduce a nominal wage aggregate:

\[
W_t^* \equiv \left( \int W_t^* (j) \frac{1}{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}}
\]  
\( (15) \)

Dixit-Stiglitz demand functions give us labor demand for each household in terms of that household’s relative wage. The higher the relative wage of household \( j \), the lower the labor demanded as a fraction of total labor hired by the firm:

\[
L_{C,t}^* (j) = \left( \frac{W_t^* (j)}{W_t^*} \right)^{-\varepsilon} L_{C,t}^*
\]  
\( (16) \)

\[
L_{NT,t}^* (j) = \left( \frac{W_t^* (j)}{W_t^*} \right)^{-\varepsilon} L_{NT,t}^*
\]  
\( (17) \)

Define “aggregate output” or real GDP as:

\[
Y_t^* \equiv \kappa Y_{C,t}^* Y_{NT,t}^{1-\chi}
\]  
\( (18) \)
Real GDP is the result of deflating nominal GDP by the GDP deflator, which is defined as:

\[
G_i^* \equiv P_{C,i}^* P_{NT,i}^{1-\chi}
\] (19)

The distinction between the CPI (consumer prices) and the GDP deflator (producer prices) will be much more important in this model than in the previous one. The GDP deflator measures the extent to which Australian households are resetting their wages and making locally produced goods more expensive, while the CPI also measures fluctuations in import prices.

### 4.4.3 Optimal wage setting

In each period, a randomly selected fraction \(1 - \omega\) of households can reset its wage. The wage-resetting problem is, in principle, the same as the household optimization problem stated above with an extra control variable, the reset wage \(W_i^*\). However, the problem can be simplified greatly by noting that any terms in the household utility function not affected by the choice of the reset wage may be dropped. We are left with the objective function:

\[
E_t \left\{ \sum_{k=0}^{\infty} (\beta \omega)^k u \left( C_{t+k}^* (j), L_{t+k}^* (j) \right) \right\}
\] (20)

where the function \(u (\cdot)\) is the period utility function, which is now maximized with respect to the budget constraint (12) with the reset wage substituted in:

\[
W_r^* L_{t+k}^* (j) + D_{t+k}^* (j) = P_{t+k}^* C_{t+k}^* (j)
\] (21)

A second simplification in this problem is to write the household’s labor supply \(L_{t+k}^* (j) \equiv L_{C,t+k}^* (j) + L_{NT,t+k}^* (j)\) as a function of the reset wage \(W_r^*\). Because it is not optimal to set the reset wage so low that there is excess labor demand, the household engineers labor supply to exactly equal labor demand under the selected reset wage. Appendix A shows that this condition can be written as:

\[
L_{t+k}^* (j) = \left( \frac{W_r^*}{W_{t+k}^*} \right)^{-\epsilon} L_{t+k}^*
\]
The full problem is solved in Appendix A. Intuitively, households set their wage to a markup over a weighted average of projected marginal costs during the period over which they are not able to reset their wage.

4.4.4 The natural rate of output

In this type of model, it is useful to compare the true rate of output with its natural rate, which would prevail under flexible prices. The “output gap” between the two may be a target of monetary policy. Appendix A shows that the natural rate of log output in Australia is:

\[ y_{n,t}^* = -\frac{1}{1 + \phi} \mu \]  

(22)

where \( \mu \) is the log of the steady-state wage markup over marginal cost. Intuitively, the household would normally work for 1 hour, as in the non-monetary model, but it is trying to earn a monopolistic rent by working slightly less. The bigger the markup it can charge, the less it works.

4.4.5 AS curve

Intuitively, a positive output gap occurs when households are working too much; they would like to reset their wages upward. Those who are able to raise their wages in period \( t \) also raise the costs of Australian firms, which respond by raising prices. These higher prices are measured as an increase in the GDP deflator, \( \pi_t^{\delta^*} \).

To make this notion precise, we combine the solution to the wage-resetting problem with the definition of the natural rate of output. We can show (see Appendix A) that time-\( t \) GDP deflator inflation depends on future expected inflation and the current output gap:

\[ \pi_t^{\delta^*} = \beta E_t (\pi_{t+1}^{\delta^*}) + \zeta (y_t^* - y_n^*) \]  

(23)

in which:

\[ \zeta \equiv (1 + \phi) \lambda \]  

(24)

\[ = (1 + \phi) \frac{(1 - \omega)(1 - \beta \omega)}{\omega (1 + \phi \epsilon)} \]  

(25)

The coefficient \( \zeta \) measures the pass-through from the output gap to current infla-
tion, assuming future expected inflation is held constant.

4.4.6 AD curve

The model’s AD curve comes from the regular Euler (IS) condition:

\[
c^*_t = E_t (c^*_{t+1}) - (i^*_t - E_t \pi^*_t - \rho - f^* (z_t))
\] (26)

where \( \pi^*_t \) is CPI inflation. The unusual term \( f^* (z_t) \) is simply the precautionary saving term that is generally dropped when log-linearizing the Euler condition. We need to keep this term since it is the source of the currency risk premium. The argument of the \( f^* (\cdot) \) function, \( z_t \), is a vector representing the current state of the economy; the state includes both the current level of productivity \( z_t \) and the wage distribution at time \( t \).

Assuming either a peg or a flexible exchange rate, is possible to show that \( f^* (z_t) \) is constant, so the inclusion of this term does not create an obstacle to solving the model as a system of log-linear equations. This analytical tractability, however, is simply a convenient result of assuming log utility over consumption; in general, one would have to run simulations or use higher-order approximations. Moreover, we are still retaining the standard log-linearizations in deriving the Phillips curve, so although we have removed the approximation error in computing the currency risk premium from consumption processes, the consumption processes themselves are subject to the standard approximation error in this type of model.

By using relationships between consumption and output and between the CPI and the GDP deflator, we can transform this equation into:

\[
y^*_t - y^*_n = E_t (y^*_{t+1} - y^*_n) - (i^*_t - E_t \pi^*_{t+1} - \rho - f^* (z_t))
\] (27)

which is our AD curve. The details are shown in Appendix A. Note that \( \rho + f^* (z_t) \) is the “natural rate of interest” here.

4.5 America

America is different from Australia in two major ways:

- Wages are flexible. This assumption just simplifies things without taking away any of the intuition.
As in the real model, the production technology is different; commodity imports are used to produce the finished good, and both non-tradable and finished good output may be subject to TFP shocks.

4.5.1 American households

As in Australia, the American household’s utility is Cobb-Douglas with finished good share $\chi$:

$$C_t \equiv \kappa C^\chi_{F,t} C^{(1-\chi)}_{NT,t}$$  \hspace{1cm} (28)

the CPI $P_t$ is defined analogously.

The representative household’s utility function is:

$$U_t = E_t \sum_{k=0}^{\infty} \beta^k \left( \ln C^*_{t+k} - \frac{N_{t+k}^{1+\phi}}{1+\phi} \right)$$  \hspace{1cm} (29)

The American budget constraint is

$$C_t P_t = W_t N_t$$  \hspace{1cm} (30)

4.5.2 American production

The U.S. has two sectors, a non-tradable sector and a finished-goods-producing sector:

$$Y_{F,t} = Z_t L_{F,t}^\alpha Y_{C,t}^{*1-\alpha}$$  \hspace{1cm} (31)

$$Y_{NT,t} = Z_t L_{NT,t}$$  \hspace{1cm} (32)

where $Z_t$ is total factor productivity, $L_{F,t}$ the labor used in finished goods production, and $L_{NT,t}$ is the labor used in the non-tradable sector.

Output is defined using real value added:

$$Y_t \equiv \gamma (Y_{F,t} - \Theta_t Y_{C,t}^*)^\chi Y_{NT,t}^{1-\chi}$$  \hspace{1cm} (33)

And the GDP deflator is:

$$G_t \equiv P^\chi_{F,t} P_{NT,t}^{1-\chi}$$  \hspace{1cm} (34)
4.5.3 Terms of trade

As shown in Appendix A, under the production functions defined above, the log terms of trade follows:

\[ \theta_t = z_t - \alpha (y_t^* - y_n^*) + \ln (1 - \alpha) + \frac{\alpha}{1 + \phi \mu} \]  

(35)

Intuitively, commodity prices rise with productivity \( z_t \) as in the non-monetary model. If there is excess output in Australia (positive output gap), this increase in commodity prices will be muted, because there will be a greater supply of commodities on the market.

4.6 Summary of model

Putting the AS, AD, and terms-of-trade equations together, we get the following system, reminiscent of the baseline New Keynesian model (e.g., among others, Yun 1996; Clarida, Gali, and Gertler 1999):

\[ y_t^* - y_n^* = E_t (y_{t+1}^* - y_n^*) - (i_t^* - E_t \pi_t^* - \rho - f^* (z_t)) \]  

(36)

\[ \pi_t^* = \beta E_t \pi_{t+1}^* + \zeta (y_t^* - y_n^*) \]  

(37)

\[ \theta_t = z_t - \alpha (y_t^* - y_n^*) + \ln (1 - \alpha) + \frac{\alpha}{1 + \phi \mu} \]  

(38)

4.7 Monetary policy in the US

In the US, the central bank targets GDP deflator (equivalently, CPI) inflation to zero. It uses the well-known Taylor rule

\[ i_t = \rho + E_t \Delta c_{t+1} + f (z_t) + \psi^{US} \pi_t^S \]  

(39)

with \( \psi^{US} > 1 \) and \( f (z_t) \) being the US analogue of the term \( f^* (z_t) \).

This specification of US monetary policy rules out coordination with Australia, which seems realistic. Monetary policy in the major, non-commodity-producing nations does not seem to be run with an eye to stability in commodity exporters.

4.8 Results under a floating exchange rate

If Australia wants to float its exchange rate, we will assume that the central bank tries to replicate the flexible-price allocation. In this type of model, such an out-
come is usually achieved by targeting (setting to zero) the rate of output price inflation, \( \pi^*_t \), with a Taylor rule. Intuitively, output price inflation would occur only if wage costs are rising, and that would only happen if labor demand were above its flexible-price level. Consequently, the central bank adopts the Taylor rule:

\[
i^*_t = \rho + f^* (z_t) + \psi \pi^*_t
\]

(40)

For a more complete discussion of optimal policy rules in the open economy, and, in particular, a discussion of the right inflation metric to target, see Frankel and Chinn (1995), Huang and Liu (2005), or Anand, Prasad, and Zhang (2015).

Substituting this rule into the system (36), (37), (38) immediately shows us that this policy rule achieves an output gap of zero, with zero GDP deflator inflation. Appendix A shows that the “Taylor principle,” or \( \psi > 1 \), is required to rule out other equilibria.

This policy results in a simple, unit-elastic relationship for the nominal exchange rate:

\[
s_t = z_t + \text{const.}
\]

(41)

As before, the real exchange rate has an elasticity to productivity less than 1:

\[
q_t = (1 - \chi) z_t + \text{const.}
\]

(42)

### 4.9 Results under a peg

By definition, the nominal exchange rate is fixed at a level \( \bar{S} \). Appendix A shows that the real exchange rate is, in logs:

\[
q_t = \left(1 - \chi\right) z_t - \left(1 - \chi\right) (\alpha + (1 - \chi)) \left(y^*_t - y^*_n\right) - \frac{\mu}{1 + \phi} \]

(43)

There are two components to the real exchange rate: the \( 1 - \chi \) elasticity derived in the floating-rate solution, and an additional term increasing in the output gap. Intuitively, an increase in \( z_t \) under floating rates leads to an appreciation of the real exchange rate. But under a currency peg, the real exchange rate can’t rise quickly, since neither price levels nor the nominal exchange rate are flexible. Instead, labor costs remain temporarily too low, causing excess demand (positive output gap
The size of this effect on the real exchange rate is then proxied by a negative multiple of the output gap.

The real exchange rate can be fully solved out in terms of $z_t$, and the derivation is shown in Appendix A. The resulting elasticity of the real exchange rate with respect to productivity is:

$$\frac{dq_t}{dz_t} = \frac{1 - \chi}{\chi} - (1 - \chi)(\alpha + (1 - \chi)) \left( \frac{\eta(1 - a\beta)}{1 - a\beta + \zeta\eta} \right)$$

A full, numerical computation of the impulse response functions (again, derived in Appendix A) shows that for a typical value of $\chi = 0.5$, the flexible-price elasticity of the exchange rate to the productivity shock is 50% on impact, while the sticky-price elasticity is only 16%. The full impulse response functions are plotted in Figure 5.

## 5 Conclusions

The tight covariance between commodity prices and commodity currencies leads to a risk premium for commodity currencies. This paper has presented a simple model of the currency-commodity covariance. Labor cost disease implies that booms in commodity prices raise the cost of non-tradables, and thus raise real exchange rates at the same time. When calibrated to reasonable parameter values, this model can match currency and commodity asset price data with realistic movements in labor costs.
References


Figure 1: Commodity currencies have higher real excess returns. CMXPTR measures the extent to which a country exports commodities relative to finished goods. Each country’s average CMXPTR score from 1984 to 2000 (the final date in the NBER-Comtrade dataset) is plotted. The y-axis is the average real log excess return on that country’s currency, annualized. The labels are ISO 2-letter country codes.

The sample is based on Hassan and Mano’s (2015) selection of 36 currencies traded between 1989 and 2007, and I filter currencies that left the sample early due to Eurozone accession (most of them in 1999) and countries that never floated their exchange rate during 1985-2015. For countries that floated for only part of the sample, the averages are computed over the floating period only. I allow the Deutsche Mark (DE) to continue as the Euro after accession.
Figure 2: *Commodity currencies load strongly on commodity risks*. The above four plots compare nominal exchange rates to matched, export-weighted commodity price indexes, also measured in dollars. The exchange rates are oriented so that “up” means an appreciation of the named currency. Export weights come from the UN-Comtrade dataset. Log scale is used.
Table 3: Short-run elasticity of the exchange rate to commodity prices (baseline specification). I run quarterly time series regressions of the change in the log bilateral real exchange rate $q_{jt}$ between country $j$ and the U.S. against the change in the log of a matched, export-weighted real commodity price index. The cross-sectional correlation between the estimated elasticities and CMXPTR, a measure of commodity exports, is 0.47.

$$\Delta q_{jt} = \beta \Delta \text{cmpi}_{jt} + \alpha + \epsilon_{jt}$$

<table>
<thead>
<tr>
<th>Country</th>
<th>Estimated $\beta$</th>
<th>Standard Error</th>
<th>$R^2$</th>
</tr>
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Asterisks denote the following significance levels: *: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$. Data are quarterly, from 1995-Q1 to present (not all currencies are available for the full sample).
Table 4: Short-run elasticity of the exchange rate to commodity prices (alternative specification). I run quarterly time series regressions of the change in the log bilateral real exchange rate $\Delta q_j^t$ between country $j$ and the U.S. against the change in the log of a matched, export-weighted real commodity price index. Unlike in Table 3, I include one lag of the right-hand-side variable to reduce any bias due to non-instantaneous adjustment of the real exchange rate. The cross-sectional correlation between the estimated elasticities and CMXPTR, a measure of commodity exports, is 0.56.

$$\Delta q_j^t = \beta \Delta \text{cmpi}_j^t + \gamma \Delta \text{cmpi}_{j-1}^t + \alpha + \epsilon_j^t$$

<table>
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<tr>
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Asterisks denote the following significance levels: *: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$. Data are quarterly, from 1995-Q1 to present (not all currencies are available for the full sample).
Table 5: Long-run elasticity of the exchange rate to commodity prices. I run time series regressions of the log bilateral real exchange rate $q^j_t$ between country $j$ and the U.S. against the log of a matched, export-weighted real commodity price index. Specifying the regression in levels (as opposed to differences, as in Tables 3 and 4) is consistent with a long-run cointegrating relationship. This approach is also more comparable with the previous literature (e.g., Chen and Rogoff 2003; Cashin, Céspedes, and Sahay 2004). The cross-sectional correlation between the estimated elasticities and CMXPTR, a measure of commodity exports, is 0.55.

$$q^j_t = \beta c\text{mp}^i_t + \alpha + \epsilon^j_t$$

<table>
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<tr>
<th>Country</th>
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<td>Chile</td>
<td>0.24***</td>
<td>0.05</td>
<td>50.5%</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>0.29</td>
<td>0.21</td>
<td>2.5%</td>
</tr>
<tr>
<td>Germany/Euro</td>
<td>0.38***</td>
<td>0.07</td>
<td>26.7%</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.26***</td>
<td>0.05</td>
<td>26.8%</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>0.02</td>
<td>0.02</td>
<td>0.7%</td>
</tr>
<tr>
<td>Hungary</td>
<td>0.59***</td>
<td>0.13</td>
<td>20.3%</td>
</tr>
<tr>
<td>India</td>
<td>0.13</td>
<td>0.09</td>
<td>2.9%</td>
</tr>
<tr>
<td>Japan</td>
<td>-0.02</td>
<td>0.04</td>
<td>0.4%</td>
</tr>
<tr>
<td>South Korea</td>
<td>0.13**</td>
<td>0.04</td>
<td>12.6%</td>
</tr>
<tr>
<td>Mexico</td>
<td>0.07*</td>
<td>0.03</td>
<td>8.0%</td>
</tr>
<tr>
<td>Malaysia</td>
<td>0.06</td>
<td>0.04</td>
<td>3.1%</td>
</tr>
<tr>
<td>Norway</td>
<td>0.16***</td>
<td>0.02</td>
<td>38.8%</td>
</tr>
<tr>
<td>New Zealand</td>
<td>1.30***</td>
<td>0.17</td>
<td>43.8%</td>
</tr>
<tr>
<td>Philippines</td>
<td>0.23***</td>
<td>0.04</td>
<td>25.6%</td>
</tr>
<tr>
<td>Sweden</td>
<td>0.24***</td>
<td>0.06</td>
<td>17.6%</td>
</tr>
<tr>
<td>Singapore</td>
<td>0.12***</td>
<td>0.03</td>
<td>20.0%</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.27***</td>
<td>0.04</td>
<td>35.6%</td>
</tr>
<tr>
<td>South Africa</td>
<td>0.32**</td>
<td>0.10</td>
<td>12.7%</td>
</tr>
</tbody>
</table>

Asterisks denote the following significance levels: *: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$. Data are quarterly, from 1995-Q1 to present (not all currencies are available for the full sample). I use OLS standard errors as a conservative choice compared to the smaller ones implied by cointegration.
Figure 3: A commodity’s basis is a good proxy for its expected excess return. A commodity’s excess return is the percentage return on a strategy of going long the nearest contract and rolling into the next-nearest contract on the month-end before the original contract is scheduled to expire. The contract is assumed to be fully collateralized by T-bills. Basis is the component of the return earned if the commodity spot price does not move; it is knowable in advance. The text and Appendix C detail the construction of these variables, based on Gorton, Hayashi, and Rouwenhorst (2006).

The set of commodities is the same as in Dhume (2010), with the addition of Iron Ore 62% Fe (TSI) for delivery to Tianjin, traded on Globex. This metal has only two years of history, and is the outlier on the right of the chart; returns have been bad recently. Annualized returns are plotted.
Table 6: Consistency of currency returns and commodity risk premia. Under this paper’s theory, the average return on a commodity currency should be consistent with the average returns on the commodities it exports, adjusted for the elasticity of the currency to commodity prices.

To check this prediction, I run four cross-sectional regressions. For the left-hand side variable, in regressions (1) and (3), the expected real excess return on each currency is proxied by \( \text{rxh}_j \), the time series average. In regressions (2) and (4), the average real interest rate differential (carry) is used instead. For the right-hand side variable, in all regressions (1)-(4), the export-weighted average basis is used as a proxy for commodity expected returns, following from Figure 3. In equations (1) and (2), this commodity return measure is scaled by the estimated currency-commodity elasticity from Table 4. As a robustness check, equations (3) and (4) simply use \( \text{CMXPTR}_j \), a measure of commodity exports, in place of the estimated currency-commodity elasticity, although in this case, there is no reason for the coefficient to be near one.

\[
\begin{align*}
(1) \quad \text{rxh}_j &= \beta \left( \hat{\eta} \cdot \text{cmbasis}_j \right) + \alpha_j + \epsilon_j \\
(2) \quad r^i - r &= \beta \left( \hat{\eta} \cdot \text{cmbasis}_j \right) + \alpha_j + \epsilon_j \\
(3) \quad \text{rxh}_j &= \beta \left( \text{CMXPTR}_j \cdot \text{cmbasis}_j \right) + \alpha_j + \epsilon_j \\
(4) \quad r^i - r &= \beta \left( \text{CMXPTR}_j \cdot \text{cmbasis}_j \right) + \alpha_j + \epsilon_j
\end{align*}
\]

<table>
<thead>
<tr>
<th></th>
<th>(1) ( \text{rxh}^i )</th>
<th>(2) ( r^i - r )</th>
<th>(3) ( \text{rxh}^j )</th>
<th>(4) ( r^i - r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \hat{\eta} \cdot \text{cmbasis}_j )</td>
<td>0.60*</td>
<td>0.78*</td>
<td>0.38*</td>
<td>0.40**</td>
</tr>
<tr>
<td>S.E.</td>
<td>(0.28)</td>
<td>(0.34)</td>
<td>(0.15)</td>
<td>(0.13)</td>
</tr>
<tr>
<td>( \text{CMXPTR}_j \cdot \text{cmbasis}_j )</td>
<td></td>
<td></td>
<td>0.38*</td>
<td>0.40**</td>
</tr>
<tr>
<td>S.E.</td>
<td></td>
<td></td>
<td>(0.15)</td>
<td>(0.13)</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>19.9%</td>
<td>22.1%</td>
<td>26.0%</td>
<td>33.7%</td>
</tr>
<tr>
<td>( N )</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
</tbody>
</table>

Asterisks denote the following significance levels: *: \( p \leq 0.05 \), **: \( p \leq 0.01 \), ***: \( p \leq 0.001 \).
Table 7: *In commodity countries, real unit labor costs rise with commodity prices.* I regress 4-quarter growth in log real unit labor costs, relative to the United States, from four OECD commodity exporters (Australia, New Zealand, Canada, and Norway) on contemporaneous 4-quarter growth in log real commodity prices. Commodity prices are country-specific, export-weighted indices computed from CRB futures data. Observations are quarterly.

\[
\Delta \ln \left( \text{relative unit labor costs}_j^t \right) = \beta \Delta \ln \left( \text{export cmdty prices}_j^t \right) + \alpha_j + \epsilon_j^t
\]

<table>
<thead>
<tr>
<th>Time-Series</th>
<th>AU</th>
<th>NZ</th>
<th>NO</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta \ln \left( \text{export cmdty prices}_j^t \right)) Newey-West S.E.</td>
<td>0.40***</td>
<td>0.56***</td>
<td>0.14*</td>
<td>0.23***</td>
</tr>
<tr>
<td>\hspace{3cm}</td>
<td>(0.08)</td>
<td>(0.12)</td>
<td>(0.07)</td>
<td>(0.03)</td>
</tr>
<tr>
<td>(R^2), within-country</td>
<td>21.8%</td>
<td>27.8%</td>
<td>14.9%</td>
<td>41.9%</td>
</tr>
<tr>
<td>Num. Countries</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Min (T)</td>
<td>95</td>
<td>95</td>
<td>75</td>
<td>95</td>
</tr>
<tr>
<td>Avg (T)</td>
<td>95</td>
<td>95</td>
<td>75</td>
<td>95</td>
</tr>
<tr>
<td>Max (T)</td>
<td>95</td>
<td>95</td>
<td>75</td>
<td>95</td>
</tr>
</tbody>
</table>

Because the observations overlap, I use Newey-West standard errors with 3 lags. The OECD data are inflation- and PPP- adjusted for comparability across countries and time. The commodity price indices are inflation-adjusted using U.S. CPI. Observation start dates are: Australia (1991-Q1); Norway (1996-Q1); New Zealand (1991-Q1); Canada (1991-Q1). Asterisks denote the following Newey-West (3-lag) significance levels: *: \(p \leq 0.05\), **: \(p \leq 0.01\), ***: \(p \leq 0.001\). Data are quarterly.
Table 8: **Long-run estimates of the effect of commodity prices on unit labor costs.**
I regress log real unit labor costs, relative to the United States, from four OECD commodity exporters (Australia, New Zealand, Canada, and Norway) on log real commodity prices. Commodity prices are country-specific, export-weighted indices computed from CRB futures data. Observations are quarterly.

\[
\ln \left( \text{relative unit labor costs}_i^j \right) = \beta \ln \left( \text{export cmdty prices}_i^j \right) + \alpha^j + \epsilon^j_i
\]

<table>
<thead>
<tr>
<th>Time-Series</th>
<th>AU</th>
<th>NZ</th>
<th>NO</th>
<th>CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \ln \left( \text{export cmdty prices}_i^j \right) )</td>
<td>0.95***</td>
<td>0.89***</td>
<td>0.45***</td>
<td>0.47***</td>
</tr>
<tr>
<td>S.E.</td>
<td>(0.11)</td>
<td>(0.17)</td>
<td>(0.03)</td>
<td>(0.025)</td>
</tr>
<tr>
<td>( R^2, \text{within-country} )</td>
<td>43.0%</td>
<td>22.2%</td>
<td>73.2%</td>
<td>77.7%</td>
</tr>
<tr>
<td>Num. Countries</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Min ( T )</td>
<td>99</td>
<td>99</td>
<td>79</td>
<td>99</td>
</tr>
<tr>
<td>Avg ( T )</td>
<td>99</td>
<td>99</td>
<td>79</td>
<td>99</td>
</tr>
<tr>
<td>Max ( T )</td>
<td>99</td>
<td>99</td>
<td>79</td>
<td>99</td>
</tr>
</tbody>
</table>

The OECD data are inflation- and PPP- adjusted for comparability across countries and time. The commodity price indices are inflation-adjusted using U.S. CPI. Observation start dates are: Australia (1990-Q1); Norway (1995-Q1); New Zealand (1990-Q1); Canada (1990-Q1). All time series go through 2014-Q3. Asterisks denote the following significance levels: *: \( p \leq 0.05 \), **: \( p \leq 0.01 \), ***: \( p \leq 0.001 \).
Figure 4: *US wage growth in oil states is driven by oil prices.* The two lines compare growth in oil prices over the trailing twelve months (left axis) to relative growth in nominal wages (right axis) between oil-producing and non-oil-producing states. This chart shows how commodity price changes can feed into labor costs. The oil price is the spot price of West Texas Intermediate crude.
Table 9: In oil-exporting U.S. states, nominal wages rise with U.S. oil prices. I regress the trailing 12-month change in log relative nominal wages on the 12-month change in log dollar oil prices (for WTI crude). Relative nominal wages are nominal wages in oil states divided by wages in non-oil states. Asterisks denote the following Newey-West (11 lag) significance levels: *: \( p \leq 0.05 \), **: \( p \leq 0.01 \), ***: \( p \leq 0.001 \). Data are monthly.

\[
\Delta \ln \left( \frac{\text{oil-state wage}_t}{\text{non-oil state wage}_t} \right) = \beta \Delta \ln (\text{WTI Crude Price}_t) + \alpha + \epsilon_t
\]

| \( \ln (\Delta \text{WTI Crude Price}_t) \) | 0.01***  \\ | Newey-West S.E. | (0.002) |
|---------------------------------|---------|
| \( R^2 \) | 32%  \\
| \( T \) | 79 |
Table 10: **Real wages in non-tradable professions grow with real wages in tradable professions**. Using a 30-country panel of annual OECD data, I regress annual changes in log real wages in the non-tradable sector on annual changes in log real wages in the tradable sector. I use country and time fixed effects (either separately or together) and cluster standard errors by country.

\[
\Delta \ln \left( \text{nontradable_wage}_j^t \right) = \beta \ln \left( \Delta \text{tradable_wage}_j^t \right) + \nu_j + \mu_t + \epsilon_j^t
\]

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\Delta \ln \left( \text{tradable_wage}_j^t \right))</td>
<td>0.85***</td>
<td>0.74***</td>
</tr>
<tr>
<td>Robust S.E.</td>
<td>(0.04)</td>
<td>(0.04)</td>
</tr>
<tr>
<td>Country F.E.</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Time F.E.</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>(R^2), within-country</td>
<td>58.1%</td>
<td>63.8%</td>
</tr>
<tr>
<td>Num. Countries</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Min (T)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Avg (T)</td>
<td>18.9</td>
<td>18.9</td>
</tr>
<tr>
<td>Max (T)</td>
<td>44</td>
<td>44</td>
</tr>
</tbody>
</table>

Real wages are measured as real total labor compensation divided by hours worked. Tradable industries include mining, utilities, and manufacturing. Non-tradable industries include wholesale retail trade, accommodation, food services, transportation, storage, information and communications, financial and insurance activities, professional, scientific and technical activities, and administrative and support service activities. Not included in either category are agriculture, forestry, and fishing. Asterisks denote the following significance levels: *: \(p \leq 0.05\), **: \(p \leq 0.01\), ***: \(p \leq 0.001\). Data are annual.
Figure 5: *Fixed vs. floating: the elasticity of the exchange rate to productivity shocks.* This graph shows the elasticity of the real exchange rate to productivity shocks under a calibrated sticky wage model. Under a currency peg, the real exchange rate moves much less with productivity shocks (and, by extension, commodity prices).
Appendix

Appendices A and B, which involve derivations supporting the models described in the text, are available online here. Appendix C, which describes the construction of the datasets used in the paper, follows.

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Appendix C: Data

- **Exports and imports**: To get nominal import and export values by SITC code, I use the annual NBER-Comtrade dataset available on the NBER’s website. The classification of SITC codes into “commodity” or “finished good” follows from Ready, Roussanov, and Ward (2015), except I do the classification at the 2-digit level rather than the 4-digit level, since their detailed classification is not posted online. I classify a 2-digit sector as a commodity-producing sector if the majority of the 4-digit sub-sectors are classified as such by Ready, Roussanov, and Ward.

  Export-weighted indices of commodity prices and commodity basis are constructed using the NBER-Comtrade dataset, extended to 2011 by the MIT Observatory of Economic Complexity. Exports are mapped to CRB commodity tickers by SITC code. The commodity data are discussed separately.

**Currency data (spot rates and forward rates)**. I start with all currencies with spot and 1-month forward prices available on Datastream. Within Datastream, there are several datasets providing these data; when there are conflicts, I use WMR, Thomson Reuters, BBI, and HBSC in that order of preference. I use end-of-month data.

Additionally, I make the following adjustments. First, I exclude the “offshore” Thai baht, which includes data errors, and I use the “onshore” values instead. I also remove zeros from Barclays data (in Datastream) for the Belgian franc spot and forward rate series, replacing them with a “missing observation” code. I also mark as missing the BEF forward rate series from Dec-1989 to Nov-1991, as the given values are incorrect.
I compute forward discounts from forward and spot prices, and use them to measure interest rate differentials.

I filter out currencies during periods in which they did not have a floating exchange rate. “Not floating” is defined as scoring less than 9 on the Ilzetzki, Reinhart and Rogoff (2011) fine classification of exchange rate regimes. This is a monthly classification, so when I take time-series averages, I use only the periods during which the currency was actually floating.

To deal with the formation of the Euro, I allow the Deutsche Mark to continue as the Euro after accession. Whether the other Eurozone currencies are included depends on the application; for long-run cross-sectional comparisons, I exclude them, because many of them became highly correlated with the mark before accession, and thus do not really constitute independent observations.

I use two subsamples. For constructing trading strategies, I simply use the entire set of floating-rate currencies on the dates that are available, that have whatever data are necessary to include or exclude them from a trade. This includes 40 currencies (not necessarily all at the same time).

I also use a “long-history” sample for cross-sectional comparisons, so that various moments can be measured without large standard errors. To construct it, I start with Hassan and Mano’s (2015) selection of 36 currencies traded between 1989 and 2007, and I filter currencies that left the sample early due to Eurozone accession (most of them in 1999). This sample includes following countries: Australia, Canada, Czech Republic, Denmark, Germany, Hungary, India, Japan, Malaysia, Mexico, New Zealand, Norway, the Philippines, Poland, South Africa, Sweden, Switzerland, Taiwan, Thailand, the United Kingdom, South Korea, and Singapore.

- **Commodity data (spot prices and basis).** Spot price and commodity basis data are provided by the Commodity Research Bureau (CRB). CRB provides a CD with historical pricing data on the whole futures curve for many (not just the most-traded) futures.
Since true spot market prices are often observed imperfectly, I follow Gorton and Rouwenhorst (2006) and use as a proxy the price of the first nearby future.

Basis measures the carry earned from holding a long futures position. It is computed as the first nearby futures price divided by the second nearby futures price, annualized by a factor of 365/(calendar days between the expiry of the two futures), and expressed as an annual arithmetic net return.

For LME-traded metals, the spot price is treated as the first nearby price, the 3-month forward price is used as the second nearby price, and the time between the two contracts is assumed to be 90 days.

Commodity returns are calculated as the excess return on a strategy of going long the nearest contract and rolling into the next-nearest the month-end before the original contract is scheduled to expire. The contract is assumed to be fully collateralized by T-bills. See Gorton, Hayashi, and Rouwenhorst (2006) for details.

The set of commodities is the same as in Dhume (2010), with the addition of Iron Ore 62% Fe (TSI) for delivery to Tianjin, traded on Globex.

- **Consumer prices.** I use monthly, quarterly, and annual consumer price index data from the International Monetary Fund’s IFS (International Financial Statistics) dataset.

- **Export share of NGDP:** To get nominal exports as a share of nominal GDP, I use annual data from the Penn World Table, version 8.1, available from the University of Groningen’s website.

- **U.S. consumption:** I use quarterly real GDP data from the BLS. Consumption is the sum of nondurable and services consumption.

- **Oil prices:** I use end-of-month spot values of West Texas Intermediate (WTI) oil, taken from FRED (series MCOILWTICO).

- **U.S. state-level nominal wages:** My wage data are from FRED, titled “Average hourly earnings of all employees: total private in [State]”. These series
are not seasonally adjusted and come from the Bureau of Labor Statistics. A sample series identifier, for Alabama, is SMU01000000500000003. These data are monthly.

- **CMXPTR.** To develop a measure of commodity exports, I follow Ready, Roussanov, and Ward (2014) and introduce the variable CMXPTR, defined for country $j$ for year $t$ as

$$CMXPTR^i_j \equiv \left( \frac{\text{net exports of basic goods} + \text{net imports of complex goods}}{\text{gross trade in all goods}} \right)^j_t$$

When aggregating across time, I use the average CMXPTR value during the period 1985-1994. Figure 6 shows that the time series of CMXPTR seem quite intuitive.
Table 11: The export-weighted commodity price indexes used here are consistent with similar numbers published by central banks. The above table compares the export weights I used for Australia in 2009, which come from the UN-Comtrade dataset, with those published by the RBA. Only categories with more than a 0.1% share of exports in the Comtrade dataset are shown above. “NR” means “not reported” in the RBA dataset. I have aggregated some categories together to make the classifications comparable. The RBA data are from Changes to the RBA Index of Commodity Prices, 2013 by Tim Robinson and Hao Wang, http://www.rba.gov.au/publications/bulletin/2013/mar/3.html

<table>
<thead>
<tr>
<th>COMTRADE export weight</th>
<th>RBA export weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>32.9%</td>
</tr>
<tr>
<td>Iron Ore</td>
<td>27.1%</td>
</tr>
<tr>
<td>Crude Oil</td>
<td>8.9%</td>
</tr>
<tr>
<td>Gold</td>
<td>8.7%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>7.9%</td>
</tr>
<tr>
<td>Aluminum</td>
<td>5.1%</td>
</tr>
<tr>
<td>Wheat</td>
<td>2.4%</td>
</tr>
<tr>
<td>Nickel</td>
<td>1.7%</td>
</tr>
<tr>
<td>Copper</td>
<td>1.5%</td>
</tr>
<tr>
<td>Lead</td>
<td>0.9%</td>
</tr>
<tr>
<td>Sugar</td>
<td>0.6%</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.6%</td>
</tr>
<tr>
<td>Cattle</td>
<td>0.5%</td>
</tr>
<tr>
<td>Cotton</td>
<td>0.3%</td>
</tr>
<tr>
<td>Silver</td>
<td>0.2%</td>
</tr>
</tbody>
</table>
Figure 6: **CMXPTR values for four countries.** This variable, which goes from -1.0 to 1.0, measures the extent to which a country is a commodity exporter.
Figure 7: *Comparison of the RBA’s export-weighted commodity price index with the one used in this paper.* The two metrics are quite similar, although the RBA measure is smoother in the 1990s. The main difference between the two is that my measure uses futures prices for matched commodities, while the RBA index is directly sourced from company reports of export prices to the Australian government.
Figure 8: **U.S. oil states.** Texas, North Dakota, Oklahoma, Louisiana, Pennsylvania, Wyoming, New Mexico, Colorado, Arkansas, Utah, Kansas, and West Virginia (Deutsche Bank, Ferro 2015, amcharts.com). These states are highlighted in blue below.
Figure 9: **Real exchange rate and real commodity price index for Australia.** Computed at a quarterly frequency because the RBA releases CPI data only at a monthly frequency.
Figure 10: **Real exchange rate and real commodity price index for Norway.** Computed at a quarterly frequency.
Figure 11: **Real exchange rate and real commodity price index for Canada.** Computed at a quarterly frequency.