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Purchasing power parity across eight worlds[☆]

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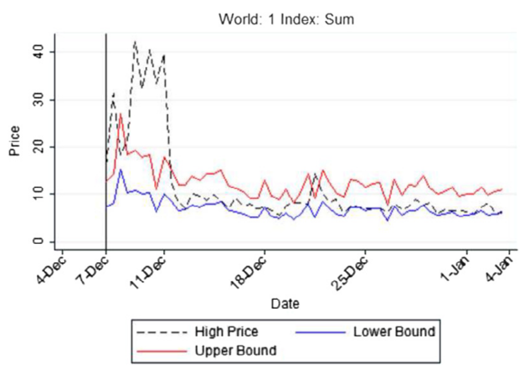
HIGHLIGHTS

- Varying trade barriers have conspired against confirming PPP in empirical work.
- We test for PPP in a natural macro experiment in 8 replicas of World of Warcraft.
- This simplified environment allows us to calculate a time-varying band of inaction.
- We find that prices stay within the band of inaction, and are highly correlated.
- Non-linear tests also find strong support for PPP across all 8 worlds.

GRAPHICAL ABSTRACT



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ABSTRACT

PPP has been remarkably hard to confirm in empirical work. Conspiring against it are data and modeling issues, in addition to barriers to trade that create a "band of inaction". We circumvent these obstacles via a natural macro experiment in the virtual game World of Warcraft. This simplified environment allows us to model and calculate the band of inaction, and test for PPP across eight replicas of the game. In addition, our data covers a major aggregate shock to the game, called Cataclysm, which lets us observe markets' reactions to the shock, and track price levels of newly created goods. We find that price levels remain within the band of inaction, and are highly correlated. When price levels diverge, arbitrage opportunities arise, and the price level differentials quickly become mean-reverting.

1. Introduction

Purchasing Power Parity (PPP), the straightforward theory that real prices of goods across countries should converge, has been remarkably difficult to confirm in empirical work. Rogoff (1996) described the PPP puzzle as "the embarrassing resiliency of the random walk model," where PPP does not hold in the short-run, and convergence is in the range of 4–5 years. Taylor (2001) argues that improved non-linear econometric techniques, and

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higher quality data – higher frequency, longer datasets, and more countries – may help solve the puzzle.

However, despite some improvements in data quality and methods, continuing research on this topic has still not reached a definite consensus. For instance, recent studies find no or little support for PPP (Arize et al., 2015; Huang and Yang, 2015; Su and Roca, 2014), while others find evidence to support it (Bergin et al., 2013; Cuestas and Regis, 2013; Kim et al., 2015; Li et al., 2015).

Additional obstacles may also prevent PPP across countries. Balassa (1964) and Samuelson (1964) point to differences in productivity across tradable and non-tradable sectors as potentially preventing price convergence. Differing exchange rate regimes across countries and time, and non-homogeneous baskets of goods across countries cause additional data limitations. Transaction costs, including transportation, time and information costs, tariffs and non-tariff trade barriers, and non-competitive markets that prevent arbitrage also conspire against PPP.

These barriers create a band of inaction (BoI), a region where the costs outweigh the benefits of arbitrage. Further complicating matters, these buffer zones are difficult to measure, in addition to the possibility that they can change over time. All this may prove a towering challenge to empirical work on PPP.

We take a different approach, in that we test for PPP in the largest online game, World of Warcraft (WoW). This environment is free of transportation costs, non-tariff trade barriers, differing exchange rate regimes, and other obstacles that may be found in the real world. This allows us to theoretically model and empirically test a time-varying band of inaction. By studying a macroeconomic natural experiment in a simplified world, we are able to circumvent the obstacles that have challenged empirical work on PPP, and demonstrate its validity in this way. Fisher (2001) follows a similar approach to ours, in that it designed a laboratory experiment where subjects trade currencies to purchase goods, and finds strong evidence in support of PPP.

We build on the initial work of Morrison and Fontenla (2013) by using high quality data that allows us to observe when price levels leave the BoI, and how fast they revert back. In addition, our data covers a major aggregate shock to the game, called Cataclysm, which lets us observe markets' reactions to the shock, and track price levels of newly created goods. We also test the data with both the regime-changing ESTAR model developed by Kapetanios, Shin & Snell (KSS) (2003), and the bounded random walk (BRW) model with reflective boundaries from Nicolau (2002).

The nascent literature on virtual environments supports the theory that virtual economies behave much like real economies. Harrison et al. (2011) discuss virtual worlds, and argue that their sophistication and realism successfully recreate real world decision making environments. Castronova et al. (2015) summarize research in virtual economies, and conclude that ''the label 'virtual', while useful in a descriptive way, does not identify anything economically unique.''

This letter contributes to the PPP puzzle discussion by employing data that one could consider as ideal, that cannot be found in the real world. By being able to measure simplified trade barriers and thus the BoI, and using high-frequency data, we find support for Rogoff's (1996) presumption that bands of inaction and higher quality data should help solve the PPP puzzle.

2. Environment

World of Warcraft is the largest virtual world, with a peak of over 12 million subscribers in 2010. To accommodate the amount of players, WoW has been divided into more than 200 stand-alone worlds, with an average population of 15,000 active players per world. Each world is separated into two countries that share a physical border. Players choose a world and country, create an avatar, and move through levels by completing quests, producing goods, and accumulating both goods and the in-game currency, gold.[1]

WoW allows for both national and international trade, which takes place in eBay-style auction houses. When an agent places an auction, a deposit based on the value and duration of the auction is required. If the auction is successful, the deposit is returned with the auction's earnings, minus a fee. If the auction is unsuccessful, the deposit is forfeit, but the agent can sell the good to a game-generated merchant for the merchant sale value (*msv*). The *msv* is therefore the price floor of a good, set by the game developers.[2]

While the national and international markets have the same rules, both deposits and fee schedules are higher in the international market. In particular, the fee for a within-country transaction is 5%, while the international tariff is 15%. Auction lengths are 12, 24, and 48 h, with the seller international deposits being 75, 150, and 300% of the *msv*.

Given that the game allows for international trade, arbitrage opportunities may exist if prices of the same good differ enough between the two countries. Specifically, an arbitrage opportunity exists for an agent if

$$U(Benefits - Costs) > 0 \tag{1}$$

with

$$Benefits = \phi\, p_h + (1-\phi)\, msv \tag{2}$$

$$Costs = p_l + \phi\, 0.15\, p_h + (1-\phi)\,\lambda\, msv + \xi, \tag{3}$$

where ϕ is the probability of a successful auction, p_h is the (high) sale price, and p_l is the (low) price of the good that the arbitrageur purchases in the low-price country. λ is the vector of deposits weighted by their respective auction durations. Finally, $\xi \geq 0$ is the time and information cost for the agent to act on the arbitrage opportunity.

Notice that the trade costs reflected in Eq. (3) are per unit costs, which in the real world are a relatively small source of international trade costs compared to other costs such as fixed transactions costs, interest costs, non-tariff trade barriers, and other costs related to trade policies. Again, the simplicity of our environment is what allows us to measure the BoI and test for PPP.

To test for PPP, we transform Eqs. (2)–(3), to price levels instead of individual prices, the probability of a successful auction ϕ becomes the overall share of successful auctions, while λ incorporates the weighted average of auction lengths.

Given the above, we can calculate the BoI as the region where

$$U(0.85\phi p_h - p_l + (1-\phi)(1-\lambda)msv - \xi) \leq 0, \tag{4}$$

where the upper bound is the above equation set equal to zero, and the lower bound is p_l.

3. Data

Our data comes from the auction markets within World of Warcraft. Data collection began on Dec. 4, 2010, and ended on Sept. 17, 2011. The game developers provide real-time listings of all auctions in all countries and worlds. With the help of code that scanned all auction houses in each world once per hour, we generated a historical record of all auctions. We randomly selected eight worlds, and collected information for the nine most traded

[1] For an expanded description of WoW and its market structure, see Morrison and Fontenla (2013).

[2] In case of an unsuccessful auction, agents could also choose to re-post the goods for auction, or keep them, instead of selling it for the *msv*. We evaluate our empirical specifications with these options, and find that our results remain qualitatively the same.