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Policy Uncertainty, Trade, and Welfare: Theory and Evidence for China and the United States†

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We examine the impact of policy uncertainty on trade, prices, and real income through firm entry investments in general equilibrium. We estimate and quantify the impact of trade policy on China's export boom to the United States following its 2001 WTO accession. We find the accession reduced the US threat of a trade war, which can account for over one-third of that export growth in the period 2000–2005. Reduced policy uncertainty lowered US prices and increased its consumers' income by the equivalent of a 13-percentage-point permanent tariff decrease. These findings provide evidence of large effects of policy uncertainty on economic activity and the importance of agreements for reducing it. (*JEL* D72, F13, F14, O19, P33)

One of the most important economic developments of the last 20 years is China's integration into the global trading system. The world's share of imports from China between 1990 and 2010 rose from 2 to 11 percent. For the United States, that increase was even larger, rising from 3 to 19 percent. This has translated into more than a tenfold increase in the share of US manufacturing expenditure on Chinese goods and there is evidence that this has contributed to declines in both US prices (cf. Auer and Fischer 2010) as well as manufacturing employment and local wages (cf. Autor, Dorn, and Hanson 2013). Figure 1 shows that most of this trade boom occurred after China's accession to the World Trade Organization (WTO), which has led some authors to argue that the accession may have reduced trade costs faced

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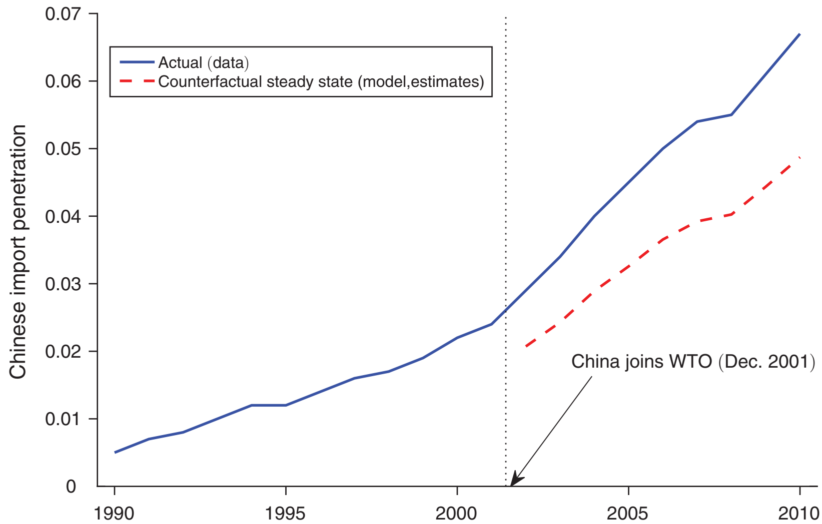

Figure 1. Chinese Import Penetration in United States: Actual versus Counterfactual under Policy Uncertainty

Notes: Import penetration ratio defined as manufacturing imports from China as share of total US expenditure on manufacturing (total shipments − net exports). Counterfactual line adjusts Chinese imports as if uncertainty reintroduced in any year after 2001. See Appendix B for further details.

by Chinese exporters.[1] But US-applied trade barriers toward China remained largely unchanged at that time.

We argue that China's WTO accession significantly contributed to its export boom to the United States through a reduction in US trade policy uncertainty. Specifically, China obtained permanent most favored nation (MFN) status with accession, which ended the annual US threat to impose high tariffs. China obtained temporary MFN in 1980 and never lost it, but it came close. In the 1990s, after the Tiananmen Square protests, Congress voted on a bill to revoke MFN status every year and the House passed it three times. Had MFN status been revoked, the United States would have reverted to Smoot-Hawley tariff levels and a trade war may have ensued. In 2000, for example, the average US MFN tariff was 4 percent, but if China had lost its MFN status it would have faced an average tariff of 31 percent. After WTO accession, the Chinese Foreign Trade Minister pointed out that by establishing "the permanent normal trade relationship with China, [the United States] eliminated the major long-standing obstacle to the improvement of Sino-US… economic relations and trade."[2]

To examine this argument, we build a model that allows us to interpret, measure, and quantify the effects of trade policy uncertainty (TPU). We obtain structural estimates of key policy uncertainty parameters and use them to quantify the implications for aggregate prices, the welfare of US consumers, and other outcomes. We focus on the role of TPU for investment and prices in part because of their importance in

[1] Autor, Dorn, and Hanson (2013) make this point and also cite other motives for this export growth. China's income has risen, driven by internal reforms (many in the 1990s) with a subset targeted to exports (Hsieh and Klenow 2009; Blonigen and Ma 2010).

[2] "China-US Trade Volume Increases 32 times in 23 years—Xinhua Reports." *BBC Summary of World Broadcasts,* February 18, 2002.

the context of the MFN debate. For example, the US decision to delink MFN from China's human rights record was described as having "removed a major issue of uncertainty" and MFN renewal would have an impact on investment and reexports that "will remove the threat of potential losses that would have arisen as a result of revocation." US business leaders argued that "…the imposition of conditions upon the renewal of MFN [was] virtually synonymous with outright revocation. Conditionality means uncertainty."[3] They lobbied Congress to make MFN permanent (Zeng 2003). At the same time, congressional research reports highlighted the higher consumer prices that would result if MFN was ever revoked (Pregelj 2001). We will argue that our approach and results have broader important implications and contribute to the growing literature on the impact of economic policy uncertainty and the role of trade agreements.

Our model captures the interaction between uncertainty and investment by modeling the latter as sunk costs and thus generating an option value of waiting. This basic theoretical mechanism is well understood (see Bernanke 1983; Dixit 1989), and there is some evidence that economic uncertainty, as proxied by stock market volatility, leads firms to delay investments (Bloom, Bond, and van Reenen 2007). In the international trade context, there is evidence of sunk costs to export market entry (see Roberts and Tybout 1997), but most empirical research on uncertainty's impact on export dynamics has focused on exchange rate uncertainty and finds small or negligible impacts (IMF 2010). In a general equilibrium setting, Impullitti, Irarrazabal, and Opromolla (2013) find a sunk cost model with heterogeneous firms and uncertain efficiency fits observed aggregate trade dynamics well.

Much less is known about the implications of economic policy uncertainty. Early theoretical contributions to this issue, such as Rodrik (1991), recognized the difficulty in measuring, identifying, and quantifying the causal effects of policy uncertainty. Recent work is tackling these difficult issues. For example, Baker, Bloom, and Davis (2016) construct a news-based index of policy uncertainty and find it helps predicting declines in aggregate output and employment. Our focus and empirical approach are considerably different. We use applied policy and counterfactual policy measures, both of which are observable in our setting, to directly estimate the effects of policy uncertainty on economic activity. In order to identify the effects of TPU, we explore both variation over time and countries (capturing the differential reduction in the probability of a trade war after WTO accession) and across industries (since they would face different tariffs if a trade war broke out and differ in their sunk costs).

To guide the estimation and quantification we develop a dynamic heterogeneous firms model with TPU. We build on Handley and Limão (2015) and extend it in three ways. First, firms can invest not only to enter foreign markets but also to upgrade their export technology. This allows changes in uncertainty to affect the extensive margin (new exporters) and the intensive margin (continuing exporters with upgraded technology).[4] Second, the exporting country is allowed to be large

[3] Quotes from, respectively, "HK Business Leaders Laud US Decision," *South China Morning Post*, May 28, 1994 and Tyco Toys CEO, "China MFN Status," Hearing before the Committee on Finance, US Senate, June 1996, p. 97.

[4] Evidence for both margins in China's export boom is documented by Amiti and Freund (2010) and Manova and Zhang (2009). Other evidence indicates that applied tariff changes can trigger within firm productivity increases

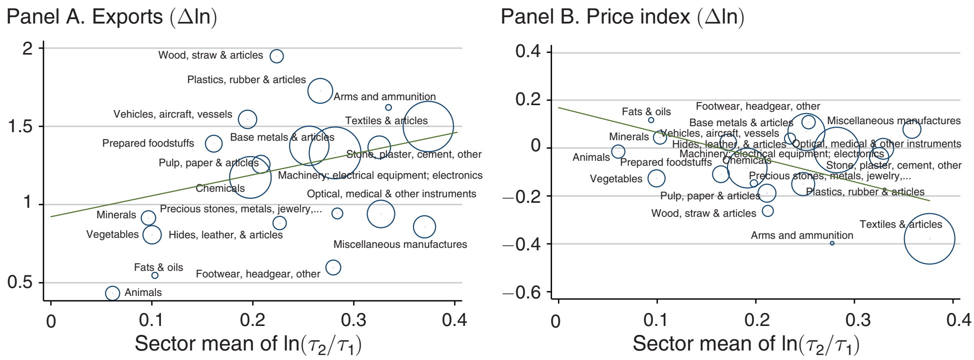

Figure 2. Sector-Level Chinese Export and Price Index Growth versus Initial Uncertainty

Notes: Simple means within sector of export and price index change versus means of initial uncertainty measured by $\ln(\tau_{2V}/\tau_{1V})$, where τ_{2V} and τ_{1V} are the column 2 and MFN tariff factors in 2000 in HS-6 industry V. Circles are proportional to the number of observations used as weights in the linear fit represented.

enough to affect the importer's aggregate outcomes. Otherwise, TPU has no significant impact on the importer. Third, entry into production is endogenous and subject to sunk entry costs such that TPU affects the formation and reallocation of firms. The model provides a number of insights. We highlight that TPU has both a direct and indirect effect on firm outcomes. The direct effect of TPU is to lower entry through an option value of waiting for exporters (fear of higher protection) and domestic firms (fear of low protection). The effect of these entry reductions is to increase the price index of the importer, which is central to the welfare gains from reforms that lower TPU. This price index increase has an indirect positive effect on exporter and domestic entry that can dominate for exporters (if initial protection is high) or for domestic firms (if initial protection is low).

As preliminary evidence and motivation for why we require a theoretical framework, consider Figure 2. In panel A we plot Chinese average export growth to the United States between 2000 and 2005 by sector against the (log) difference of the column 2 and MFN tariffs in 2000. On average, those sectors facing a relatively higher initial tariff threat in the case of MFN revocation experienced faster export growth and larger declines in prices, as shown in panel B. The exercise is suggestive, but also raises questions regarding the identification of partial effects and the quantification of the general equilibrium effects, both of which the model helps to address. First, what is a theory-consistent measure of uncertainty? The model shows it is the proportion of profits that Chinese exporters would lose if China ever lost its MFN status. We map this to observable tariff measures and then find evidence that our measure is relevant to exporters. Second, what are the necessary controls and assumptions required to identify the TPU effect and what structural parameters can we estimate? The model generates a tractable TPU-augmented gravity equation that allows us to consistently aggregate individual firm decisions to the industry level and identify the change in the probability of MFN being revoked. Moreover, the

(cf. Lileeva and Trefler 2010) so it is plausible that the same may happen due to reductions in TPU. This could account for the evidence of substantial firm-level TFP growth increases in China since 2001 (Brandt, Van Biesebroeck, and Zhang 2012).

model generates a relationship between ideal import price indices and TPU that we also estimate. Third, the model predicts these effects should only apply to trading partners where TPU changed and in industries with sunk costs of exporting.

We use variation in policies, export values, and prices across thousands of products to estimate the effects of TPU. We find nonparametric and parametric evidence that Chinese export growth in the period 2000–2005 was higher in industries with higher initial TPU. The effect is robust to controlling for applied tariff and nontariff barriers, transport costs, and sector-specific growth trends. The effect is only present in industries with export sunk costs, which we identify by exploring persistence in export behavior. Moreover, the effect is also robust to allowing for a broader set of shocks than those present in the theoretical model: namely, unobserved shocks to import demand (TPU has no direct effect on other US imports) and export supply (US TPU toward China has no direct effect on Chinese exports to non-US destinations), which rules out a large set of potential confounding factors.

We also construct industry-level ideal import price indices following Feenstra (1994) and find larger reductions in industries with initially higher TPU. This is the effect the model predicts due to new imported varieties (for which we find direct evidence) and technology upgrading. The price effect is also robust to controlling for alternative variables and unobserved import demand shocks and it is only present in high sunk cost industries. The partial effect of reducing TPU was to lower the average US industry price indices for Chinese imports by at least 15 log points and the corresponding aggregate index by slightly more.

The significant partial effects of TPU on import prices leads us to quantify its aggregate effects. In Section III we characterize the general equilibrium effects of TPU by solving for the model in changes. We derive the impacts on firm entry, sales, and prices (foreign and domestic) and how they depend on key features of the policy regime: current and future tariffs and the probability of transitioning between them. Combining this framework with a nonlinear estimate of the TPU-augmented gravity equation, we identify the reduction in the probability of MFN revocation. To isolate and quantify the aggregate effects of reducing TPU we then evaluate the impacts of the estimated shock to this structural parameter. The counterfactual implies an aggregate Chinese export increase of 32 log points, which is about one-third of the observed growth in this period. The predicted changes in the US import price index, domestic manufacturing firm sales, employment, and entry are also consistent with the observed changes during this period. The counterfactual import penetration if TPU had remained in place between 2002 and 2010 would have been substantially lower, as shown by the dashed line in Figure 1.

We also contribute to the long-standing question of the aggregate gains from trade. Recent work by Arkolakis, Costinot, and Rodríguez-Clare (2012) shows that import penetration and trade cost elasticities are sufficient statistics to compute those gains in a class of models. That is also the case for the deterministic version of our model, and so the gains from trade, or autarky cost, provides a useful benchmark. However, under TPU those are no longer sufficient statistics and we require the change in the ideal price index. We estimate that TPU increased that US price index (for tradables) by one-half as much as fully eliminating trade with China, or the equivalent of a permanent tariff increase of 13 percentage points. So the consumer welfare cost from TPU was about one-half of the cost of prohibiting all Chinese imports.

TPU plays a key role in evaluating the impacts of international trade agreements more broadly. Promoting trade is a central goal of the WTO, but Rose (2004) argues this institution has not succeeded whereas others argue it has (cf. Subramanian and Wei 2007). Our work highlights a trade promotion channel that, until recently, was largely missing from the analysis of trade agreements. The theoretical literature has emphasized that the central role of the General Agreement on Tariffs and Trade (GATT)/WTO is to internalize terms-of-trade effects (Bagwell and Staiger 1999). There is now evidence that countries possess market power, so their tariffs can affect their terms-of-trade, and exploit it before an agreement but less so afterward (Broda, Limão, and Weinstein 2008; Bagwell and Staiger 2011; Ludema and Mayda 2013). Moreover, the welfare cost of trade wars in the absence of such agreements are potentially large (cf. Ossa 2014). Recent theoretical work has focused on TPU. Limão and Maggi (2015) examine the role of risk aversion in the design and impact of agreements that target TPU; Horn, Maggi, and Staiger (2010) and Amador and Bagwell (2013) rely on TPU and imperfect contracting to explain a specific feature of such agreements—the use of tariff ceilings or bindings. Handley (2014) provides empirical evidence that reducing bindings increases foreign product entry. Our framework allows for a quantification of reducing such bindings; we also provide direct evidence of the welfare gains from reducing TPU and offer qualitatively new predictions. Specifically, agreements that allow a country to commit to a more stable and predictable trade policy, as the WTO claims to, can lower the probability of large swings in protection and thus increase entry not only by foreign firms but also by domestic ones in the import competing sector (and can also increase their domestic sales and employment). This outcome for domestic firms is possible when tariffs are sufficiently high, as they were when GATT 1947 was signed, which points to one of GATT's potential benefits.

The framework can also be applied ex ante to evaluate potential TPU shocks. We illustrate this through a range of counterfactual exercises where the United States unilaterally threatens to abandon or renegotiate all its trade agreements, which is extreme but plausible under the forty-fifth US president's administration. An increase in the US threat of higher tariffs on all its partners would generate considerable consumer welfare costs even if no tariffs were actually changed. If the threat was raised to a level similar to what China faced then the resulting loss in US consumer welfare would be equivalent to one-third of the cost of trade autarky.

Our research also complements the recent empirical work on the impact of Chinese exports on developed countries. Bloom, Draca, and van Reenen (2016) assess the impact of Chinese exports on wages and employment in the European Union while Acemoglu et al. (2016) and Caliendo, Dvorkin, and Parro (2015) focus on the United States. Pierce and Schott (2016) study the effects of Chinese exports on US manufacturing employment and, as an intermediate step, they estimate the reduced-form effect of column 2 tariffs on exports.[5] Our papers differ in important ways. First, our focus is on the trade, price, and consumer welfare effects. Second, we provide evidence for the central mechanism: sunk costs of exporting. Third,

[5] Therefore, independently from us, they too follow the proposal in Handley and Limão (2012, p. 44) to estimate the importance of "the US threat of nonrenewal of China's MFN status and whether its elimination in 2001 (upon China's WTO entry) can explain the subsequent export boom to the United States."

we develop a theoretical framework that contributes to the literature on agreements and gains from trade while allowing for the structural identification of parameters. Among other things, we explore the counterfactual exercises to isolate and quantify the aggregate effects of TPU on several outcomes and decompose them: e.g., we find that a large fraction of the trade and price changes is explained by a mean-preserving compression of the tariff and the rest is due to locking in tariffs below the mean.

We present the basic framework and derive the TPU-augmented gravity equation in Section I, followed by the empirical analysis in Section II. The general equilibrium solution in Section III is used for the structural estimation and quantification in Section IV. The appendices contain information on extensions, derivations, data, and robustness tests.

I. Framework and Partial Equilibrium Effects

We first describe the basic framework and firm entry decision problems, which apply throughout the paper. We then derive the effect of TPU on these decisions from the perspective of a small exporting country, one that takes foreign aggregate variables as given. We initially focus on a single industry and, in Section IE, we model multiple industries and technology upgrading, which we use to derive the TPU-augmented gravity equation. This partial equilibrium structure is sufficient to derive and empirically identify any effect of TPU on exports. But in order to quantify its effects on exporter and importer outcomes, we allow for a large exporter and endogenous domestic entry in Section III.

A. *Demand*, *Supply*, *and Pricing*

Consumers spend a fixed share of income on a homogeneous good and the remaining on a constant elasticity of substitution (CES) aggregate of differentiated goods, both tradable. Each period consumers observe current economic conditions and choose the optimal quantity of each differentiated good, q_v, to maximize utility subject to their budget constraint. The resulting CES aggregate demand is $q_v = EP^{\sigma-1}p_v^{-\sigma}$ where $\sigma > 1$ is the constant elasticity of substitution across varieties v and p_v is the consumer price. The aggregate demand shifter, E, is the total expenditure in the differentiated sector in that country and $P = \left[\int_{v\in\Omega}(p_v)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$ is the CES price index for the set of available varieties, Ω.

The supply side is also standard. There is a single factor (labor) with constant marginal productivity normalized to unity in the homogeneous good; the latter is taken as the numéraire so the equilibrium wage is unity in a diversified equilibrium. In the differentiated sector, there is a continuum of monopolistically competitive firms each producing a variety, v, with heterogeneous productivity $1/c_v$. Firms know their underlying productivity and the distribution of other firms in each market.

The consumer price, p_v, includes an ad valorem tariff, $\tau \geq 1$, so exporters receive p_v/τ per unit; domestic producers face no taxes in their market. The tariff is common to all firms in the differentiated industry. After observing τ, each firm chooses p_v to maximize operating profits taking aggregate conditions as given and correctly anticipating their equilibrium value. We allow for an ad valorem export cost, $d \geq 1$, so operating profits from exporting are $(p_v/\tau - dc_v)\,q_v$. This yields the standard markup rule over cost, $p_v = \tau d c_v \sigma/(\sigma - 1)$, and equilibrium operating profit equal to

$$\pi(a, c_v) = a c_v^{1-\sigma}, \tag{1}$$

where the *economic conditions* faced by any exporter are summarized by $a \equiv (\tau\sigma)^{-\sigma}((\sigma-1)P/d)^{\sigma-1}E$.

B. *Policy Uncertainty and Entry*

Export Entry.—The timing and information relevant for export entry are the following. At the start of each period, surviving firms observe the state, denoted by s, that includes information about (i) the set of firms active in the previous period; (ii) the current realization of the policy; and (iii) all model parameters in the start of the period. This information permits each firm to correctly infer market conditions in that state, a_s, and form rational expectations about future profits. If entry in a state maximizes the firm's expected profits net of a sunk entry cost, K, then it will enter and continue to export in the following period with probability $\beta < 1$, the exogenous probability of survival. There are no period fixed costs and thus no endogenous exit. Since the sunk and marginal costs are known and constant, the only source of uncertainty is the future value of market conditions and the timing of death.

The expected value from exporting for any firm v after entry is

$$\Pi_e(a_s, c) = \pi(a_s, c) + \mathbb{E}_s \sum_{t=1}^{\infty} \beta^t \pi(a_s', c), \tag{2}$$

where we omit the variety subscript for simplicity; $\mathbb{E}_s$ denotes the expectation over possible future states conditional on the current state's information set.

If the firm does not expect the state to change, there is no uncertainty about economic conditions and no option value of waiting to enter. In this case the firm enters if its cost is below a threshold value, c_s^D. This benchmark threshold is obtained by equating the present discounted value of profits to the sunk cost:

$$\frac{\pi(a_s, c_s^D)}{1-\beta} = K \Leftrightarrow c_s^D = \left[\frac{a_s}{(1-\beta)K}\right]^{\frac{1}{\sigma-1}}. \tag{3}$$

If future conditions are uncertain then a nonexporter must decide whether to enter today or wait until conditions improve. The optimal entry decision of a firm in state s maximizes its expected value, given by the Bellman equation

$$\Pi(a_s, c) = \max\{\Pi_e(a_s, c) - K, \beta\mathbb{E}_s\Pi(a_s', c)\}. \tag{4}$$

The solution to this optimal stopping problem takes the form of intervals of a over which a firm will enter. Under reasonable assumptions on the persistence of policy we can show that a firm will enter if economic conditions are sufficiently good. Therefore, when a is decreasing in tariffs the solution is to enter when current tariffs are below a firm-specific threshold tariff. For any given a_s, there is a marginal firm with cost equal to the threshold value, c_s^U, given by the entry indifference condition,

$$\Pi(a_s, c_s^U) = \Pi_e(a_s, c_s^U) - K, \tag{5}$$

and any firms with lower costs will enter in state s.

Production Entry.—Our estimation strategy for the partial effect of TPU on exports is valid under alternative assumptions regarding entry into production. However, the general equilibrium effects of TPU will depend on production entry decisions. We model the latter similarly to export entry: to start production, a firm requires a sunk cost, K_h, in order to activate a known technology. The firms make this decision after observing the current realization of the policy. Thus, firms with a cost below a certain threshold enter and continue to produce the following period with a fixed probability, their survival rate (there are no production fixed costs). The domestic operating profit of a home firm is $\pi_h = a_h c_v^{1-\sigma}$ where $a_h = (\sigma)^{-\sigma}\left((\sigma-1)P\right)^{\sigma-1}E$ and we assume that $K_h \geq 0$ is sufficiently small that the marginal home entrant does not export. Therefore the domestic entry thresholds for home market firms can be obtained using the expressions we derived above when evaluated at K_h, $a_{s,h}$, and β_h; specifically by using (3) if there is no uncertainty to obtain $c_{s,h}^D$ and (5) to determine $c_{s,h}^U$.

C. *Policy Regime*

To characterize the effects of TPU, we propose an exogenous policy process that captures three key states of trade policy, denoted $m = 0, 1, 2$. Standard models of trade policy consider permanently high or low protection states, where $\tau_2 > \tau_0$. These extremes can capture outcomes under no cooperation (e.g., US tariffs on Cuba or North Korea) or under a credible agreement (e.g., US tariffs on Canada or certain WTO members). To analyze the effect of TPU we add an intermediate protection state characterized by a temporary tariff $\tau_1 \in [\tau_0, \tau_2]$ that changes with probability γ. Formally, the *trade policy regime* is characterized by a Markov process with time-invariant distribution, denoted by $\Lambda(\tau_m, \gamma)$.

By allowing for three states, we can capture a rich set of situations.[6] To address the central questions, we can focus on a simple transition matrix where policy is uncertain only in the intermediate state, so $\gamma > 0$, and the extreme states are absorbing.[7] The exact interpretation of each state depends on the setting. In our empirical application the intermediate state captures China's pre-WTO period when its temporary MFN status in the United States could change with probability γ and give way to either high protection (column 2 tariffs) with probability λ_2, or low protection with probability $1 - \lambda_2$. So we can interpret WTO accession as a switch to the low state in this application. Alternatively, we can interpret the WTO accession

[6] These include any setting where there is some probability of (i) cooperation with negligible probability of increases in protection (e.g., under credible agreements); (ii) partial cooperation (e.g., when protection may increase but a credible agreement is also possible); and (iii) higher protection levels (including a trade war or even autarky).

[7] This holds if $\Lambda(\tau_{m+1}, \gamma)$ first-order stochastically dominates $\Lambda(\tau_m, \gamma)$ for $m = 0, 1$, which is what we use in Appendix AA to establish the key entry results and how they generalize if the high state is not absorbing.

as an exogenous change in policy regime, if it lead to an unanticipated change in γ (or τ_m). Thus, we derive the effects of transitions across policy states within a regime and transitions across regimes.

The three state process has two other benefits when considering countries starting in the intermediate protection state. First, it captures the two key effects of agreements: reducing applied protection and/or TPU. Second, it allows for the possibility that policy worsens for either foreign firms (higher protection state) or domestic ones (lower protection state); this generates an option value of waiting for both types of firms. These benefits will become clearer in Section III when we decompose and quantify the applied and TPU effects and account for the general equilibrium responses of domestic firms.

D. *Partial Equilibrium*

To estimate the impact of trade policy on entry and exports, we derive the effects on cutoffs from switching regimes or switching states and decompose the latter into a change in applied policy and policy uncertainty.

Tariffs are the only underlying source of uncertainty and we initially focus on a small exporting country such that changes in its exports have a negligible effect on the importer's aggregate variables, E and P.

The small country assumption implies that tariffs worsen export business conditions only via a direct effect, and there is one distinct value of a_s for each τ_m for any given value of $EP^{\sigma-1}$. Moreover, tariffs leave exporter wages unchanged at unity in any diversified equilibrium. So we do not require additional general equilibrium structure to derive the basic cutoff expressions. In Appendix AA we use this to show that the solution to the Bellman equation (4) is a single value of economic conditions above which a firm enters. Therefore, the condition in (5) implies a distinct cutoff, c_s^U, for each τ_m. The cutoff for the intermediate state, c_1^U, is proportional to its deterministic counterpart in (3) by an *uncertainty factor*, $U(\omega, \gamma)$:

$$c_1^U / c_1^D = U(\omega, \gamma); \tag{6}$$

$$U(\omega, \gamma) \equiv \left[\frac{1 + u(\gamma)\,\omega}{1 + u(\gamma)}\right]^{\frac{1}{\sigma-1}}. \tag{7}$$

If U is less than 1, then entry is reduced under uncertainty. To interpret this factor, note that $\omega \equiv (\tau_2/\tau_1)^{-\sigma} < 1$ is the ratio of operating profits under the worst-case scenario relative to the intermediate state (given no other conditions changed). The term $u(\gamma) \equiv \gamma\lambda_2\beta/(1-\beta)$ is the average spell that a firm starting at the intermediate state expects to spend under τ_2. This spell is increasing in the probabilities of exiting the intermediate policy state, γ, and then facing a higher tariff, λ_2, and surviving, β. Note that if $\gamma = 0$ then policy is fixed in all states, thus we say that there is *policy uncertainty* if $\gamma > 0$. Moreover, any increase in γ implies a higher probability of a policy change but does not change the odds of the worst- or best-case scenario. We interpret this as an increase in policy uncertainty.

From these expressions we can see that entry in the intermediate state is lower under uncertainty if and only if tariff increases are possible, i.e., $c_1^U < c_1^D$ if and only if $\tau_2 > \tau_1$ and $u(\gamma) > 0$. Note that while TPU can lead to lower or higher tariffs, it is only the possibility of high tariffs that affects export entry; if there is uncertainty but tariff increases are not possible, $\lambda_2 = 0$, then uncertainty has no impact on entry.

The entry result in (6) reflects a specific switch in policy regime: an unanticipated introduction of TPU at a given tariff. We note two simple extensions that are relevant for the empirical analysis. First, the effect of TPU on entry is monotonic ($dc_1^U/d\gamma < 0$ for all γ) so we can also test for marginal changes in TPU, e.g., whether before WTO accession Chinese exporters faced higher TPU in years when an MFN revocation seemed more likely. Second, we also want to understand the effect of agreements that are anticipated with some probability, i.e., switches to state 0, and compare them to unanticipated changes in TPU. In Appendix AA we show the cutoff in the intermediate state relative to any deterministic baseline state with tariffs τ_b is

$$c_1^U/c_b^D = U(\omega,\gamma) \times (\tau_1/\tau_b)^{-\frac{\sigma}{\sigma-1}}. \tag{8}$$

If $\tau_b = \tau_0$ this expression captures the reduction in applied policy and uncertainty from entering state 0 since, when there is no uncertainty in that state, the cutoff is equal to the deterministic value, $c_0^U = c_0^D$. Switching from the intermediate to the low state increases entry by reducing applied tariffs by τ_1/τ_0 and/or TPU. Thus, even if an agreement is anticipated with some probability, entering it can be used to identify an unanticipated elimination of TPU after we control for applied tariff changes.

The impact of eliminating TPU, as we have defined it, can be decomposed into a pure risk and expected mean effect. To understand each of these, consider the regime switch described above when we start in the intermediate state and uncertainty is eliminated. If τ_1 was at the long-run mean of the original tariff process then this uncertainty reduction is exactly a mean-preserving compression of tariffs, or a *pure risk* reduction.[8] However, if τ_1 was below its long-run mean, as will be the case in our application, then the reduction in γ has the additional effect of locking in tariffs below their expected value under uncertainty. Thus, the model will help us quantify each of these effects.

In sum, the explicit solution for the entry cutoff in equation (6) allows us to derive its elasticity with respect to γ, and the appropriate measure to capture the potential losses under the worst-case scenario, ω. Next, we show how to explore variation in this measure over industries to identify the effect of TPU.

[8] In this three state process, if state 1 has a policy τ_1 equal to the long-run mean then a decrease in γ induces a mean-preserving compression of the initial conditional policy distribution, $\Lambda(\tau_1,\gamma)$. This is one motive to use a 3-state process.

E. *TPU-Augmented Gravity*

We derive a TPU-augmented gravity equation to estimate how changes in policy uncertainty translate into export growth. This requires extending the baseline model in two dimensions. First, we model the effect of uncertainty on the intensive margin of a firm's exports. Second, we allow for industry variation in policies, which is necessary for our identification strategy.

Technology Upgrade.—We will focus on estimating the effect of changes in TPU on export growth. This growth can reflect extensive and intensive margin effects and we now show how the TPU-augmented gravity can capture both. We believe this extends the applicability of the framework to situations where both margins are potentially important. For example, most Chinese export growth to the United States in the period 2000–2005 took place in HS-10 goods that were already being exported in 2000. Some of the growth in existing products is due to new exporters but it is also plausible that existing ones grew by investing in export activities due to reduced TPU in the United States. We model one potential channel, irreversible investments by incumbent exporters to upgrade their technologies. This is consistent with the large increases in TFP growth of Chinese firms since WTO accession.[9]

To illustrate the main points in the simplest setting, consider upgrades that are specific to an export market. In particular, suppose that exporters can incur an additional sunk cost, K_z, to reduce the marginal export cost to a fraction $z < 1$ of the baseline cost d. The operating profits are then $\pi_v = a_s(zc_v)^{1-\sigma}$. In Appendix AB we show that the upgrading decision is similar to the entry decision in that it also takes the form of a cutoff cost. The upgrade cutoff is $c_{sz}^U = \phi c_s^U$. It is proportional to the entry cutoff by a constant *upgrading parameter*, $\phi \equiv \left[(z^{1-\sigma} - 1)(K/K_z)\right]^{\frac{1}{\sigma-1}}$. The upgrade cutoff is lower than the entry one if the marginal cost reduction from upgrading is sufficiently low relative to its sunk cost. This implies that the marginal entrant does not upgrade. The export entry cutoff solutions will be similar to those we derived, but only the more productive exporters will upgrade. Since ϕ is independent of tariffs, the elasticity of the upgrade and entry cutoff are exactly the same with respect to tariffs and uncertainty.

Multi-Industry Aggregation.—We define an industry V as the set of firms that draw their productivity from a similar distribution, $G_V(c)$, and face similar trade barriers. The basic structure of the model is otherwise unchanged. Namely, the policy regime is still described by a Markov process, $\Lambda(\tau_{mV}, \gamma)$ with $m = 0, 1, 2$ and it applies to each V. It thus captures our empirical setting such that if any industry V moved to the agreement state (or the high protection state) then all industries would face the same policy state.

[9] We are not aware of any direct evidence of the impact of foreign tariffs on Chinese productivity but Brandt, Van Biesebroeck, and Zhang (2012) find that firm-level TFP growth in manufacturing between 2001 and 2007 is about three times higher than prior to WTO accession, 1998–2001. Moreover, the TFP growth in the WTO period is higher for larger firms, which is consistent with our model's prediction that those are the most likely to upgrade. In future work we plan to directly estimate if there is a causal effect of TPU on Chinese firm TFP.

The export revenue in state s for firm $v \in V$ is $p_{sv} q_{sv} / \tau_{sV} = a_{sV} \sigma (z_V c_v)^{1-\sigma}$ once we plug in the optimal price and quantity from Section IA, where $z_V < 1$ for the upgraders and unity otherwise. The economic conditions variable, a_{sV}, still reflects aggregate income and price index effects but it now reflects industry-specific tariffs (and export costs). The export entry cutoff in (6) is industry-specific but otherwise the previous cutoff results are unchanged.

The mass of exporting firms in any stationary equilibrium, characterized by a constant mass of active firms, is equal to $N_V \times G_V(c_s^U)$, the total number of potential firms in industry V in the export country times the fraction of these with costs below the cutoff. Export revenue in industry V is obtained by aggregating over firms that upgrade and those that do not as follows:[10]

$$(9) \qquad R_{sV} = a_{sV} d_V^{1-\sigma} \sigma N_V \left[\int_0^{\phi_V c_{sV}^U} (z_V c)^{1-\sigma} dG_V(c) + \int_{\phi_V c_{sV}^U}^{c_{sV}^U} c^{1-\sigma} dG_V(c) \right].$$

We assume that productivity in each industry is drawn from a Pareto distribution bounded below at $1/c_V$, so $G_V(c) = (c/c_V)^k$ and $k > \sigma - 1$. Under this assumption we can obtain sharper predictions, nest a standard gravity model in our framework, and provide precise conditions under which we can identify the impact of uncertainty on exports. We integrate the cost terms in (9), use the definition of a_{sV}, and c_{sV}^U, and take logs to obtain an uncertainty-augmented gravity equation,

$$(10) \qquad \ln R_{sV} = (k - \sigma + 1) \ln U_{sV} - \frac{\sigma}{\sigma - 1} k \ln \tau_{sV} - k \ln d_V + k \ln P + \frac{k}{\sigma - 1} \ln E + \ln \zeta_V + \ln \tilde{\alpha}_V.$$

Without either policy uncertainty, $U_{sV} = 1$, or upgrading, $\zeta_V = 1$, (10) reduces to a standard industry-level gravity equation conditional on aggregate expenditure on differentiated goods, E, and the price, P (cf. Chaney 2008). The terms $\tilde{\alpha}_V$ and ζ_V are combinations of industry parameters that are time invariant.[11] Finally, all else equal, upgrading increases export levels, as reflected in ζ_V, but not the *elasticity* of industry exports with respect to U_{sV}. Thus, we can aggregate sales from all firms to estimate the impact of uncertainty on their industry exports without requiring additional information on which firms upgrade.

II. Estimation and Identification

We use the model to examine how China's WTO accession, which eliminated the annual MFN renewal debate in the United States, contributed to its export boom to the United States. We focus on industry exports, which will reflect both entry and upgrading effects. The objective of this section is to identify a causal effect of TPU

[10] We use the relationship $c_{sz}^U = \phi c_s^U$ and allow industry variation in the upgrade technology and sunk costs. Away from stationary equilibria there are additional exporters who entered in previous periods under better conditions.

[11] $\tilde{\alpha}_V \equiv \frac{N_V \sigma}{c_V^k} \frac{k}{k - \sigma + 1} \left(\frac{1}{(1-\beta) K_V} \right)^{\frac{k-\sigma+1}{\sigma-1}} \sigma^{\frac{-\sigma k}{\sigma - 1}} (\sigma - 1)^k$ and $\zeta_V \equiv 1 + \frac{K_{zV}}{K_V} (\phi_V)^k$.

on exports and test if the data is consistent with some of the model's assumptions. We use the TPU-augmented gravity equation in (10). As we show in Section III, this same equation holds even when the exporter is large enough to affect the aggregate variables. If we control for those variables, then we can identify whether TPU affected exports regardless of exporter size.

A. *Approach*

We estimate the export equation in changes for two reasons. First, it allows us to difference out unobserved industry characteristics such as entry costs, the productivity and mass of Chinese producers in V and the technology parameters in ζ_V. In the robustness tests we address the possibility that they vary over time and are correlated with TPU. Second, we are interested in the impact of the *change* in uncertainty after the United States removed the threat of column 2 tariffs due to China's WTO entry. So our baseline uses the time-difference of (10),

$$\Delta \ln R_V = f\left(\frac{\tau_{2V}}{\tau_{1V}}, \gamma\right) + b_\tau \Delta \ln \tau_V + b_d \Delta \ln D_V + b + e_V, \tag{11}$$

where $\Delta \ln$ represents the difference between post- and pre-WTO periods. The coefficient $b_\tau = -k\sigma/(\sigma - 1) < 0$ is the effect of applied tariffs (conditional on the uncertainty factor). We model ad valorem export costs, d_V, as a function of observable shocks given by the ad valorem equivalent of insurance and freight, $\Delta \ln D_V$, and an i.i.d. error term contained in e_V. The changes in transport costs allow us to identify the Pareto shape parameter, $b_d = -k$. Any changes in *aggregate* expenditure on differentiated goods or its price index are captured in the constant term, b. The null hypothesis under the model is that prior to WTO accession there is a positive probability of column 2 tariffs, i.e., $\gamma\lambda_2 > 0$, and thus f is increasing in τ_{2V}/τ_{1V} if the accession reduced γ. If the accession eliminated uncertainty then $f = -(k - \sigma + 1)\ln U(\tau_{2V}/\tau_{1V}, \gamma)$. Under the regime switch interpretation, the model allows for $\gamma > 0$ even after entry. In that case $f = (k - \sigma + 1)\Delta \ln U(\tau_{2V}/\tau_{1V}, \gamma)$ where changes in U reflect either changes in tariffs or γ. In the period we consider τ_{2V}/τ_{1V} is nearly constant within industries, so f captures changes in γ. So in this case f is also increasing in τ_2/τ_1.

Standard trade models with a gravity structure yield a restricted version of (11) with $f = 0$ that is nested in our model. Even if uncertainty is important, our functional form assumptions may not be satisfied by the data. We address this as follows. First, we provide nonparametric estimates of the impact of τ_{2V}/τ_{1V} on export growth. Second, we control for observed changes in policies and trade costs and provide semiparametric estimates of the impact of policy uncertainty—imposing only the gravity structure that is common in trade models without uncertainty. Third, we test the model's functional form for f and perform numerous robustness checks (e.g., the possibility of industry-specific growth trends and unobserved demand and supply shocks). Fourth, after introducing the general equilibrium structure we provide a nonlinear structural estimate of the corresponding term for f that we then use to quantify the impact of TPU.

We also test if the uncertainty effect is predominant in high sunk cost industries, as the model predicts.

B. *Data and Policy Background*

We combine trade and policy data from several sources. US import trade data at the HS-10 level for several years is obtained from the NBER Harmonized System Imports by Commodity and Country. These data are concorded over time and used to compute ideal price indices and aggregated to the HS-6 level for the price and export growth regressions. We obtained US tariff schedules via the World Bank's WITS. The source of other policy measures we use are described in Appendix B. The cost of insurance and freight is reflected in the import data. We convert all tariff and transport cost data to their iceberg form (e.g., from 10 percent to $\ln\tau = \ln 1.1$).

There are 5,113 HS-6 industries in the 1996 classification; China exported in 3,617 of these in both 2000 and 2005 to the United States. The baseline analysis focuses on the industries traded in both years so that a log growth rate exists. These industries account for 99.8 percent of all export growth from China to the United States in this period.[12]

The following policy background is useful for understanding the timing choice for our baseline estimates. Uncertainty remained about both China's accession to the WTO and its permanent normal trade relations (PNTR) as late as 2000 due to tense foreign and economic relations. In October 2000, Congress passed the US-China Relations Act granting PNTR but its enactment was contingent on China's accession to the WTO. Protracted accession negotiations and a jet fighter collision meant that in the summer of 2001 Congress again voted on whether to revoke MFN. China joined the WTO on December 11, 2001 and the United States effectively enacted PNTR on January 1, 2002. This strongly suggests that uncertainty about column 2 tariffs remained at least until 2000 and that it was not reduced until 2002. We will focus on the growth between 2000 and 2005 but show that the basic effect is present for other relevant periods.

C. *Partial Effect Estimates of TPU on Exports*

Table 1 provides summary statistics for our baseline sample. Export growth from 2000 to 2005 averaged 128 log points (lp) across HS-6 industries, with substantial variation across them; the standard deviation is 168 lp. This industry variation suggests that the boom can't simply be explained by aggregate shocks. Table 1 also shows substantial variation in column 2 tariffs across the industries.

All else equal, the model predicts lower initial export levels in the pre-WTO period for industries with higher potential profit losses if there was a possibility of tariff increases. If WTO accession reduces or eliminates this probability, we should observe relatively higher export growth in those industries. For any given value of σ the industry ranking of potential profit loss is determined by τ_{2V}/τ_{1V} so we use this ratio to partition the sample into the columns in Table 1 labeled Low (bottom tercile of τ_{2V}/τ_{1V}) and High TPU industries. Export growth in high uncertainty industries is 19 lp higher, a mean difference that is statistically significant. The export

[12] Our baseline sample is smaller because it focuses on the 94 percent of HS-6 lines where tariffs are levied on an ad valorem basis, other HS-6 lines have only specific tariffs. We show the results are robust to this and the zero trade flow industries in Section IID.

Table 1—Summary Statistics by Pre-WTO Policy Uncertainty

	Uncertainty		
	Low	High	Total
Chinese export value growth (Δln, 2005 − 2000)[a]	1.16	1.35	1.28
	[1.77]	[1.62]	[1.68]
Chinese export price index growth (Δln, 2005 − 2000)[a]	−0.07	−0.14	−0.11
	[0.70]	[0.69]	[0.69]
Chinese export variety growth (Δln, 2005 − 2000)[a]	0.27	0.35	0.32
	[0.46]	[0.41]	[0.43]
MFN tariff (ln), 2000	0.03	0.04	0.04
	[0.04]	[0.05]	[0.05]
Column 2 tariff (ln), 2000	0.16	0.39	0.31
	[0.10]	[0.12]	[0.16]
Ratio of column 2 to MFN tariff	1.14	1.42	1.33
	[0.09]	[0.14]	[0.18]
Uncertainty (pre-WTO)[b]	0.30	0.64	0.52
	[0.18]	[0.09]	[0.20]
Change in MFN tariff (Δln, 2005 − 2000)	−0.002	−0.004	−0.003
	[0.01]	[0.01]	[0.01]
Change in transport costs (Δln, 2005 − 2000)	−0.01	−0.002	−0.005
	[0.10]	[0.08]	[0.09]
Observations[c]	1,124	2,087	3,211

Notes: Simple means with standard deviations in brackets. Low: subsample of industries in the bottom tercile of pre-WTO uncertainty (ranked by τ_2/τ_1); High refers to the rest of the sample. Total includes the full sample used in baseline Table 2.

[a] Test of mean difference across samples significant at least at the 5 percent level.

[b] Potential profit loss measure if MFN revoked pre-WTO: $1 - (\tau_1/\tau_2)^{\sigma}$, using $\sigma = 3$.

[c] Total observations for price index change: 2,579 HS-6 industries used in baseline Table 4. Total observations for variety growth (number of traded HS-10 varieties with an HS-6 industry): 1,051 and exclude industries with censored varieties (traded in both 2000 and 2005). High and low bins for price and variety are defined on the baseline sample.

growth distribution for high TPU industries first-order stochastically dominates the one for low TPU industries, as shown by the respective kernel densities in panel A of Figure 3 and confirmed via a Kolmogorov-Smirnov test. Panel A of Figure 4 provides further nonparametric evidence of this relationship by estimating a local polynomial regression of export growth on $\ln(\tau_{2V}/\tau_{1V})$. We confirm the higher growth in high initial uncertainty industries, via a mean test, and a nonnegative relationship over the domain.

Semiparametric Evidence and Functional Form.—Using a semiparametric approach, we can control for other determinants of export growth and test for specific functional forms of the uncertainty term. Several trade models yield a gravity equation that is a special case of (11) with the implicit restriction that $f = 0$. We use the residuals from that restricted estimation to determine how τ_{2V}/τ_{1V} affects f without imposing functional forms. Using a double residual semiparametric regression (Robinson 1988) we find that τ_{2V}/τ_{1V} has a significant effect on subsequent export growth net of tariff or transport cost changes. This result is robust to including 21 sector dummies in the restricted regression to net out any heterogeneous growth trends in Machinery, Textiles, Footwear, and the remaining 18 other sectors that the UN defines as coherent groups of HS-2 categories.

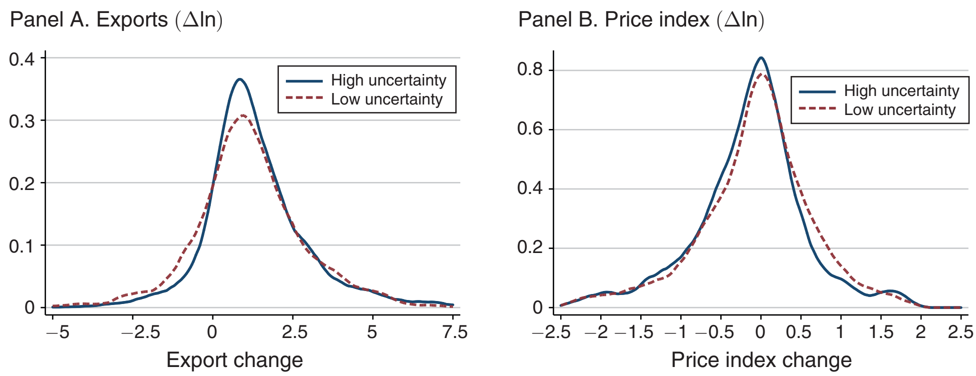

FIGURE 3. CHINESE EXPORT AND PRICE INDEX GROWTH IN HIGH VERSUS LOW UNCERTAINTY INDUSTRIES

Notes: Epanechnikov kernel density estimates. High uncertainty defined as the top two terciles of ratio of US column 2 to MFN tariff in HS-6 industry V. Low uncertainty is the bottom tercile. Equality of distributions rejected with p-value of 0.001 (panel A) and 0.009 (panel B) in Kolmogorov-Smirnov tests. See text for details of price index calculation.

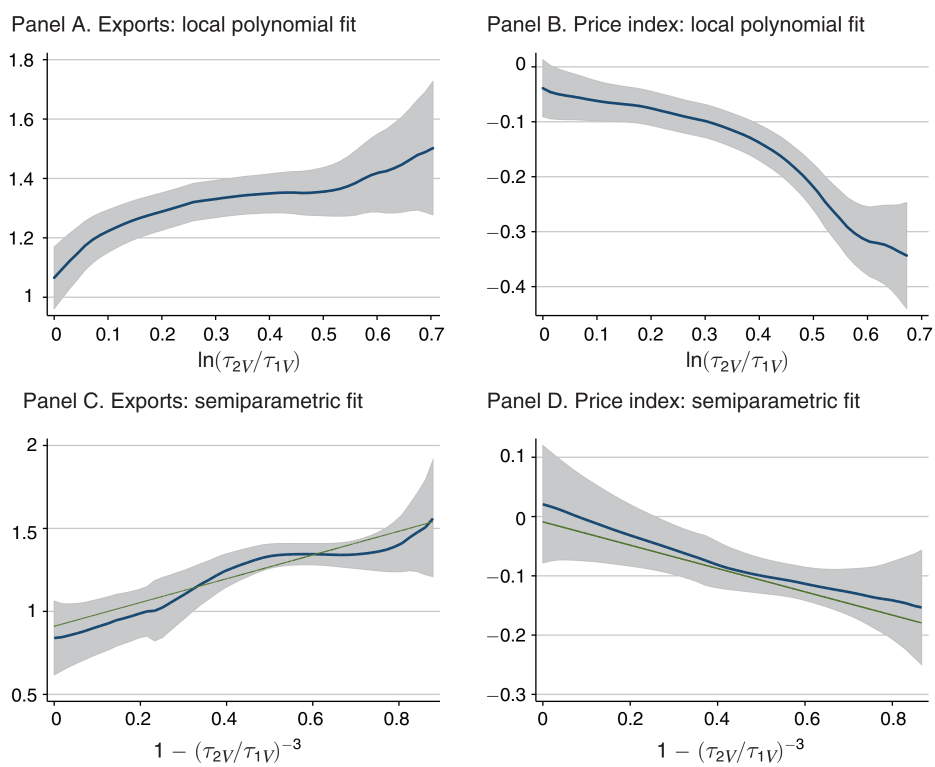

FIGURE 4. CHINESE EXPORT AND PRICE INDEX GROWTH (Δln) VERSUS INITIAL POLICY UNCERTAINTY

Notes: Panels A and B are a local polynomial fit on $\ln(\tau_{2V}/\tau_{1V})$, where τ_{2V} and τ_{1V} are the column 2 and MFN tariff factors in 2000 in HS-6 industry V. Panels C and D regress log export and log price index growth on changes in transport costs, tariffs, and on sector dummies. The linear fit uses OLS and also includes $-(\tau_{2V}/\tau_{1V})^{-3}$, which the semiparametric uses as an argument of the local polynomial estimated using the Robinson (1988) semiparametric estimator. We plot the fit against $1-(\tau_{2V}/\tau_{1V})^{-3}$ for ease of comparison with the uncertainty variable used in the baseline OLS regressions.

Table 2—Chinese Export Growth (US, Δln): Baseline Estimates, 2000–2005

	(1)	(2)	(3)	(4)
Uncertainty pre-WTO	0.743	0.791	0.716	0.734
[+]	[0.154]	[0.150]	[0.186]	[0.184]
Change in tariff (Δln)	−9.967	−4.34	−7.356	−4.25
[−]	[4.478]	[0.676]	[5.060]	[0.677]
Change in transport costs (Δln)	−2.806	−2.893	−2.795	−2.833
[−]	[0.455]	[0.450]	[0.456]	[0.451]
Constant	0.851	0.843		
	[0.0853]	[0.0850]		
Observations	3,211	3,211	3,211	3,211
R^2	0.03	NA	0.05	NA
Sector fixed effects	No	No	Yes	Yes
Restriction p-value (F-test)	0.204	1	0.536	1

Notes: Robust standard errors in brackets. Predicted sign of coefficient in brackets under variable. Uncertainty measure uses US MFN and column 2 Tariffs to construct profit loss measure at $\sigma = 3$. All specifications employ OLS and 2 and 4 impose theoretical constraint on tariffs and transport cost coefficients: $b_\tau = b_d(\sigma/(\sigma - 1))$. Sectors defined by the 21 HS sections.

In panel C of Figure 4, we plot the resulting semiparametric fit and see it is increasing in $1 - (\tau_{2V}/\tau_{1V})^{-3}$, the potential profit loss measure when $\sigma = 3$. The figure also shows the partial effect of this measure obtained from OLS estimation of (11), so controlling for tariffs, transport costs, and sector trends. We see the parametric estimate lies everywhere within the shaded area representing the semiparametric 95 percent confidence interval. Because we can't reject their equality, we will use the OLS specifications with $\sigma = 3$ as a baseline from which to perform robustness tests. We also test if the semiparametric fit is equal to alternative parametric fits that are linear or log-linear in τ_{2V}/τ_{1V} and find they are rejected by the data. This suggests that reduced-form measures of column 2 tariffs should not be used for quantitative predictions. Partially because the nonlinearity implies a smaller effect of τ_{2V} at high tariffs where trade would be negligible.

Parametric OLS Estimates.—The semiparametric evidence supports approximating the uncertainty term using $b_\gamma \times \left(1 - (\tau_{2V}/\tau_{1V})^{-3}\right)$ in (11). When we approximate U_V linearly around $\gamma = 0$ and use (7) we have the following structural interpretation of $b_\gamma^{OLS} = [(k - \sigma + 1)/(\sigma - 1)]u(\gamma)\,g \geq 0$. We first present parametric estimates of b_γ and check their robustness to two potentially important sources of omitted variable bias.

Baseline.—The ordinary least squares (OLS) results in Table 2 are consistent with the structural interpretation of the parameters. In column 1 we see that b_γ is positive and significant. As predicted, this implies that industries with higher initial potential losses grew faster after WTO accession. The coefficients on tariffs and transport costs are negative and significant. The estimation equation contains an over identifying restriction, $b_\tau = b_d\sigma/(\sigma - 1)$, that we cannot reject. We therefore reestimate the model in column 2 with this restriction, which increases the precision of the estimates. One reason for the increase in precision for the tariff coefficient is the small variation for this variable in this period.

Sector-Level Growth Trends and Unobserved Heterogeneity.—The preliminary evidence in panel A of Figure 2 showed a positive relationship between the average export growth and the mean of $\ln(\tau_{2V}/\tau_{1V})$ by sector. If most of the variation in TPU or export growth was across sectors then we would worry their relationship would be proxying for an omitted sector effect. To explicitly control for this possibility, we reestimate the baseline including a set of 21 sector dummies. The results in columns 3 and 4 of Table 2 are similar to the baseline and show the robustness to potential sources of omitted variable bias, such as differential changes across sectors in productivity, sunk costs, upgrading parameters, FDI, and Chinese barriers on intermediates.

D. *Robustness*

The baseline results are robust to several potential issues, which we outline below. The online Appendix includes the associated tables and a detailed discussion of each issue.

Nontariff Barriers.—In Table A2 we control for changes in HS-6-level nontariff barriers, including the removal of the Multi-fiber quotas, which does not affect the baseline estimates.

Elasticity of Substitution, *Outliers and Sample Selection*.—In Table A3 we find that the qualitative impact of TPU is robust to (i) alternative assumptions regarding the elasticity of substitution used to construct this variable; (ii) downweighting outliers using a robust regression procedure; and (iii) extending the sample to incorporate zero trade flows (by calculating midpoint growth rates) and HS-6 industries that do not have ad valorem but have specific tariffs.

Processing Trade.—In Table A3 we drop the HS-6 industries where processing trade is most prevalent (Kee and Tang 2016) and continue to find a significant impact of TPU. This specification controls for several potential omitted variables (e.g., Chinese policy toward the input purchase, transformation, and resale of output to a foreign firm) and indicates TPU affected a broad set of industries.

Capital/Labor Intensity.—In Table A4 we find the TPU effect is robust to controlling for capital/labor intensity and marginally stronger for industries where that intensity is highest.

Unobserved Export Supply Shocks.—We addressed omitted variable bias thus far by controlling for specific variables at the HS-6 level and for unobserved contemporaneous sector shocks. In Table A5 we control for unobserved HS-6 industry Chinese export supply shocks common across destinations. First, we provide a placebo test and find no effect from regressing Chinese export growth to the European Union and Japan on the US TPU measure. Second, we pool these observations with the US sample and include HS-6 effects and identify a positive differential growth effect of US TPU on Chinese exports to the United States (relative to other markets in the same industry). Thus, the baseline estimates are robust to controlling for narrowly defined Chinese supply shocks common across destinations, including any Chinese policy changes induced by WTO accession and Chinese technology changes.

Unobserved Import Demand Shocks.—If US import demand increased in industries with higher uncertainty, then the baseline estimates could be biased upward. Such shocks would also increase US imports from other countries and cause them to be correlated with the TPU measure. However, in Table A6 we find no evidence of this. US import growth from nonpreferential trade partners was not significantly affected. Pooling these imports and those from China allows us to control for HS-6 effects and thus any unobserved US import demand shocks. The differential effect of TPU on Chinese imports is positive and significant. We perform a similar test focusing on a specific control, Taiwan. This country also acceded to the WTO in January 2002 but unlike China it never faced an annual renewal process for its MFN status so the model would predict little or no effect of TPU. The results in Table A6 support this prediction.

Pre-Accession Growth Trends.—The baseline focuses on export growth over the period 2000–2005. Any pre-accession growth trends correlated with TPU could bias these estimates. In Table A7 we find no significant effect of the uncertainty measure in 1996 on Chinese export growth to the United States in the years 1996–1999. We then extend the baseline sample to include the pre-accession period and perform a difference-in-differences estimation—we find the baseline estimates are robust to controlling for HS-6 specific growth trends.

Timing of TPU Shocks.—In Table A8 we provide estimates from a yearly panel in levels between 1996 and 2006 and find a similar effect to the baseline. Moreover, the timing of the effect matches the WTO accession. The increased growth in higher TPU industries only becomes significant in 2002. We find lower import *levels* in the period 1996–2001 in industries with higher TPU but that effect is similar across those years suggesting that, prior to WTO accession, minor changes in the legislation or in the relations between the United States and China did not significantly affect Chinese firms' beliefs about losing the MFN status.[13]

E. *Additional Evidence: Sunk Cost Channel*

The baseline provides an average elasticity of exports to TPU across all industries. We now test if that elasticity is only present in industries with sunk costs of exporting, as predicted by the model. Doing so requires a measure of those costs and, since none is readily available, we estimate it by exploiting variation in the persistence of exporting over time. A standard approach (Roberts and Tybout 1997) is to use firm-level data to estimate a probability model where, after conditioning

[13] These insignificant changes in γ during the period 1996–2001 are also consistent with the lack of variability in the vote share to revoke MFN status in the House of Representatives. According to the Congressional Quarterly Almanac, that share increased slightly from 33 percent in 1996 to 40 percent in 1997 and remained around that level (except for 2000, 34 percent). We also constructed and found that a news index of US TPU did not fall significantly during the period 1996–2002 but did so between 2002 and 2006, both of which are consistent with the panel estimates of changes in γ. We thank two referees for these suggestions.

on firm characteristics to capture their current incentive to participate, any correlation with lagged participation provides evidence of sunk costs. We apply a similar approach but use HS-10 product data and estimate export persistence parameters, b_V^{sunk}, industry-by-industry.

In online Appendix C4 we argue that the estimates appear reasonable and provide additional details on the estimation and identification.[14] We classify industries as having relatively higher sunk costs if their t-statistic for b_V^{sunk} is higher, which indicates we can be more confident of rejecting $b_V^{sunk} = 0$. More specifically, the top two terciles of the regression sample with higher t-statistics are classified as higher sunk cost relative to those in the bottom tercile.

In panel A of Table 3 we find no effect of TPU on Chinese exports in low sunk cost industries (column 1). In contrast we find a positive and significant effect for the high sunk cost subsample (column 2). This provides strong evidence for the model's option value of waiting uncertainty channel.

The heterogeneity of TPU due to sunk costs is not driven by its correlation with import demand shocks. US imports from Taiwan are not significantly affected by TPU either on average (Table A6) or in either sunk cost subsample (Table 3, columns 3 and 4). Moreover, in the last two columns of Table 3, we pool Taiwan and China and include HS-6 effects to control for the possibility that sunk costs have some unobserved correlation with the uncertainty measure. We find a positive and significant differential effect of TPU on Chinese trade (relative to Taiwan) in high sunk cost industries but not in low.[15]

The heterogeneity of TPU due to sunk costs is also not driven by its correlation with export supply shocks. Recall that we found no average effect of US TPU on Chinese exports to the European Union. In panel B of Table 3 we also find no differential effect of TPU on Chinese exports to the European Union between high and low sunk costs (columns 3 and 4). When we pool Chinese exports to the United States and European Union in columns 5 and 6 and include sector-country and HS-6 industry dummies, we find a positive and significant differential effect on China's export growth to the United States in the high sunk cost industries and none in the low, as the model predicts.[16]

In sum, there is strong support for the sunk cost channel and the effect is robust to controlling for unobserved demand and supply shocks.

F. *Partial Effect Estimates of TPU on Prices and Entry*

Prices.—The model predicts that a reduction in TPU lowers the ideal consumer import price index due to the entry of new varieties and a reduction in the prices of existing ones if there is technology upgrading. For industry V in state s this index for

[14] To minimize the impact of the episode we study on the persistence estimates, we use data for the pre-accession period, 1996–2000, and focus on the effect of lagged export participation on current export participation for each HS-10 product-country variety for all US nonpreferential trade partners, excluding China.

[15] These estimates also include a full set of sector-country dummies with standard errors clustered on industry. The significance is similar when using 500 bootstrap replications to account for the generated regressor.

[16] We employ the same sunk cost measure as in panel A, which requires only a similar industry ranking of these costs when exporting to the United States or the European Union.

Table 3—US Import and Chinese Export Growth: Sunk Cost Heterogeneity and Unobserved Shocks, 2000–2005

	China		Taiwan		Pooled	
US imports from:	Low	High	Low	High	Low	High
Sunk cost sample:	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. US import growth (Δln)*: robustness to unobserved HS-6 import demand shocks in high versus low sunk cost industries*						
Uncertainty pre-WTO (US)	−0.611	1.105	−0.593	0.0486		
	[0.393]	[0.280]	[0.414]	[0.297]		
Uncertainty pre-WTO (US) × **1**(China)					0.0663	1.026
					[0.517]	[0.383]
Change in tariff (Δln)	−9.59	−12.0	−6.699	−19.3		
	[13.30]	[7.107]	[11.91]	[6.484]		
Change in transport costs (Δln)	−2.28	−4.51	−3.21	−5.18	−1.12	−4.67
	[1.200]	[0.743]	[0.892]	[0.724]	[0.880]	[0.797]
Observations	759	1,519	759	1,519	1,518	3,038
R^2	0.08	0.09	0.13	0.11	0.32	0.43
Sector × country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
HS-6 fixed effects	No	No	No	No	Yes	Yes
	US		EU−15		Pooled	
Chinese exports to:	Low	High	Low	High	Low	High
Sunk cost sample:	(1)	(2)	(3)	(4)	(5)	(6)
Panel B. Chinese export growth (Δln)*: robustness to unobserved HS-6 export supply shocks in high versus low sunk cost industries*						
Uncertainty pre-WTO (US)	0.0363	0.816	0.492	−0.336		
	[0.313]	[0.263]	[0.302]	[0.241]		
Uncertainty pre-WTO (US) × **1**(China)					−0.444	1.144
					[0.409]	[0.315]
Change in tariff (Δln)	−2.659	−7.703	5.845	−12.43	−1.15	−9.563
	[11.49]	[5.805]	[6.075]	[3.166]	[5.881]	[3.876]
Observations	975	1,945	975	1,945	1,950	3,890
R^2	0.047	0.037	0.066	0.05	0.03	0.04
Sector × country fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
HS-6 fixed effects	No	No	No	No	Yes	Yes

Notes: Robust standard errors in brackets clustered on HS-6 industry in columns 5 and 6. Uncertainty pre-WTO is defined as in the baseline US sample. Total sample in columns 1 and 2 reduced relative to Table 2 because sunk cost estimates not available for all HS-6 industries. The change in the US MFN tariff does not vary across nonpreferential partners and is not identified in panel A when HS-6 industry effects are included. The uncertainty coefficient is also not separately identified for non-Chinese imports in panel A or non-US exports in panel B. For panel A, the sample is the subset of HS-6 products with trade in 2000 and 2005 for US imports from both Taiwan and China. For panel B, the sample is the subset all HS-6 products with trade in 2000 and 2005 exported by China to the United States and European Union.

an exporter x is defined by $P_{sV,x} \equiv \left[\int_{\Omega_{sV}^{x}} (p_{vs})^{1-\sigma}\right]^{1/1-\sigma}$.[17] In online Appendix C5, we establish that changes in this index between 2005 and 2000 have an exact log-linear representation in terms of uncertainty and trade costs, yielding

$$(12)\quad \Delta \ln P_{V,x} = -\left(\frac{k}{\sigma - 1} - 1\right)(-\ln U_V) + b_\tau^P \Delta \ln \tau_V + b_d^P \Delta \ln D_V + b^P + e_V,$$

[17] These reflect the consumer prices inclusive of any tariffs and transport costs. A change in this price index could still be consistent with a negligible change in the aggregate US price index if the expenditure share on those goods is negligible.

Table 4—Chinese Price Index and Variety Growth (US, Δln), 2000–2005

	Price index				Variety			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Uncertainty pre-WTO	−0.284	−0.217	−0.418	−0.483	0.0736	0.0606	0.243	0.200
	[0.0689]	[0.0828]	[0.173]	[0.223]	[0.0309]	[0.0380]	[0.0722]	[0.0907]
MFN tariff (Δln)	5.137	0.560	9.839	6.829	−5.170	−4.066	−3.196	−2.792
	[1.608]	[1.682]	[4.313]	[4.497]	[0.957]	[1.024]	[1.179]	[1.185]
Transport cost (Δln)	−0.435	−0.460	−0.477	−0.465	−0.227	−0.200	−0.514	−0.504
	[0.254]	[0.248]	[0.626]	[0.620]	[0.0909]	[0.0897]	[0.165]	[0.160]
Observations	2,579	2,579	907	907	2,579	2,579	1,051	1,051
Industry sample	HS6	HS6	HS4	HS4	HS6	HS6	HS6, uncensored	HS6, uncensored
R^2	0.02	0.06	0.02	0.06	0.03	0.06	0.03	0.07
Sector fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
Uncertainty price impact (Δln)[a]								
Average price	−0.15	−0.11	−0.22	−0.25				
Aggregate price	−0.17	−0.13	−0.25	−0.28				

Notes: Robust standard errors in brackets. All specifications employ OLS. Constant or sector fixed effects included but not reported. The dependent variable is the ln change in the ideal price index of Chinese varieties sold in the United States between 2000 and 2005 calculated at the industry level; see online Appendix C for details. Sample: we use the subset of industries where value and quantity data are available and price changes are defined for at least one HS-10 variety in 2000 and 2005 for the industry (HS-6 in columns 1–2 or HS-4 in columns 3–4). The HS-6 sample trims outliers in the 2.5 percent tails of the dependent variable. Columns 7 and 8 exclude censored HS-6 industries, i.e., those where all their HS-10 categories had positive trade in both periods (these observations contain no information about whether the number of firms exporting in that industry changed).

[a] Uncertainty impacts are weighted effects of all industries. For average effect the weight is the mean of the uncertainty variable. For the aggregate we weight the uncertainty by the ideal CES price index relative weight of each industry as described in online Appendix C.

where b^P contains the aggregate terms and e_V is an error term. Higher initial uncertainty, i.e., lower U, generates lower price changes because $k > \sigma - 1$ (for a finite first moment of exports). We use the same linear approximation of $\ln U_V$ as the OLS gravity estimates of equation (11).[18]

We compute the change in the price indices for each industry using the approach in Feenstra (1994), which captures the new varieties and changes in the price of existing ones. We define varieties at the HS-10 product-country level, as in Broda and Weinstein (2006). We continue to assume a common σ so any correlation between the price change and our measure of TPU does not reflect variation in the elasticity.

Similarly to export growth, we first provide nonparametric and semiparametric evidence. First, the distribution of price changes is lower for high TPU industries and present across the full range of TPU, as seen in panel B of Figures 3 and 4. Second, in panel D of Figure 4, we show the result is also present in the semiparametric estimates after controlling for tariffs, transport costs, and sector effects.

Table 4 presents the estimates for equation (12) showing that industries with higher initial TPU indeed had larger price reductions. In column 1 we see the uncertainty effect estimated at the same level as export growth, HS-6, is significant and robust to controlling for sector effects (column 2).[19] The partial effects of uncertainty

[18] Thus, $\ln U_V \approx -\frac{ug}{\sigma-1}\left(1-\left(\tau_{2V}/\tau_{1V}\right)^{-3}\right)$ and the estimated OLS coefficient is $b_\gamma^P = -ug\frac{k-(\sigma-1)}{(\sigma-1)^2}$.

[19] The number of observations is lower than the gravity regressions because quantity is not always consistently observed and because the price index is only defined for HS-6 industries where at least one variety is traded in both periods, which may introduce a sample selection bias. Any such bias should be mitigated by recomputing the price

on prices are the following. First, using column 1, the average reduction in the price index is 15 log points at the mean of initial TPU. Second, the aggregate import price index change is a weighted average of the industry-level changes; applying those same weights to the estimates of TPU in each industry we obtain its impact on the aggregate import price index: 17 log points.

The baseline price index results are also robust to controlling for HS-6 industry-specific shocks, e.g., to tastes and quality. We apply the approach used to control for import demand shocks in Table A9. For each HS-6 we compute an additional aggregate import price index, which reflects all nonpreferential partners trading with the United States and pool them with the Chinese observations to estimate the differential effect of TPU. The first column of Table A9 shows that industries where Chinese exporters faced higher initial TPU had larger price reductions if the good was imported from China but that same measure of TPU had no significant effect on the price index measure from the remaining countries. In column 2 we find a significant differential effect of TPU on the Chinese goods prices even after controlling for HS-6 effects. We find similar results in columns 3 and 4 when we restrict the control group to Taiwan. All the results control for sector-country growth shocks and cluster standard errors at the HS-6 level.

Evidence on Channels: Entry, Upgrading, and Sunk Costs.—The price index effects are the relevant ones for consumer welfare. But we can provide some additional evidence for the entry and upgrading channels and the role of sunk costs highlighted by the model.

The model predicts that at least a fraction $G(c_{sV}^{U})$ of Chinese firms in industry V export to the United States. In Section IB, we derive an exact log-linear representation of entry in terms of uncertainty and trade costs that yields the following estimation equation:

$$\Delta \ln n_V = k(-\ln U_V) + b_\tau^n \Delta \ln \tau_V + b_d^n \Delta \ln D_V + b + e_V, \quad (13)$$

where b captures aggregate changes and e_V is an error term. The predicted signs match those for the export equation. Using the changes in the number of traded HS-10 products as a proxy for entry, we find TPU reductions lead to entry in the same sample where we found it reduced the price index. Moreover, all other variables are significant and have the predicted sign (Table 4).[20]

Directly testing the effect of TPU on upgrading requires data on export technology expenditures, which are not available. Nevertheless, we can provide indirect evidence. In the absence of upgrading, the model predicts no effect of uncertainty

change at a higher level of aggregation. In column 3 we do so and regress it on the HS-4 average of the TPU and trade cost measures, which yields a stronger effect of TPU. We focus the quantification and robustness on the more conservative HS-6 estimates.

[20] The magnitude of the uncertainty coefficient in column 5 of Table 4 is attenuated toward zero because entry is measured with error when we use product data. The attenuation reflects measurement error whenever a *true* variety is defined at a level finer than the HS-10, thus we do not use these estimates for quantification. This issue is potentially important in industries where all HS-10 categories within an industry already had positive trade in both periods, so the growth in the number of measured variety is zero but true variety may have increased or decreased. We address this in column 7 by dropping those industries; the sign and significance are similar to those in the full sample but the impact of uncertainty triples.

TABLE 5—CHINESE PRICE INDEX AND VARIETY GROWTH: SUNK COST HETEROGENEITY (US, Δln), 2000–2005

	Price index		Variety	
	(1)	(2)	(3)	(4)
Uncertainty pre-WTO				
× High sunk cost indicator	−0.449	−0.320	0.096	0.082
	[0.0816]	[0.0923]	[0.0423]	[0.0485]
× Low sunk cost indicator [~0]	−0.009	−0.062	0.019	0.030
	[0.118]	[0.130]	[0.0396]	[0.0471]
MFN tariff (Δln)	4.429	0.332	−4.710	−3.788
	[1.610]	[1.687]	[0.950]	[1.012]
Transport cost (Δln)	−0.446	−0.465	−0.217	−0.196
	[0.253]	[0.248]	[0.0896]	[0.0888]
High sunk cost indicator	0.165	0.103	0.029	0.029
	[0.0793]	[0.0810]	[0.0324]	[0.0345]
Constant	−0.047		0.055	
	[0.0658]		[0.0230]	
Observations	2,579	2,579	2,579	2,579
R^2	0.02	0.06	0.04	0.07
Sector fixed effects	No	Yes	No	Yes

Notes: Robust standard errors in brackets. All specifications employ OLS. Dependent variables and sample described in notes to Table 4. High sunk cost indicator is 1 for industries in top two terciles of export sunk cost estimates ranked by t-statistic, as described in text.

on the prices of continuing varieties. The ideal price index for Chinese imports in industry V is composed of a weighted average of changes in unit values of HS-10 varieties traded in 2000 and 2005 plus a variety growth term. If a reduction in TPU only operated by inducing export entry, then the model predicts an increase in the continuing variety component for industries with higher initial TPU, i.e., an increase in average prices since the entrants would be less productive. In online Appendix Figure A2 we find the opposite.[21] This evidence that continuing varieties have substantially lower prices in industries with higher TPU is not consistent with a basic version of our model where TPU only affects entry (nor one with quality upgrading); the finding requires a channel whereby reductions in TPU lower the prices of continuing varieties. One such channel is export technology upgrading.

In Table 5 we examine whether the baseline price and entry effects are stronger in high sunk cost industries. We interact the TPU measure with indicators for high and low sunk cost industries, defined as before. We find significant effects of TPU on prices and entry for high sunk cost industries but no significant effects for low, as the model predicts.

In sum, we have documented a strong and robust relationship of TPU on export values and prices of Chinese goods sold in the United States and provided evidence for the channels highlighted by the model. The nonnegligible share of expenditure on those goods suggests this episode affected aggregate outcomes in the United States. To quantify these we model the general equilibrium effects of TPU.

[21] The local polynomial fit in Figure A2 of the continuing variety component against TPU shows a significant negative relationship, which is also robust to controlling for changes in tariffs, transport costs, and sector effects in a parametric setting similar to the one used for the full price index in Table 4.

III. General Equilibrium Effects of Policy Uncertainty

To quantify and decompose the GE effects of TPU, we now allow countries to be large enough to affect aggregate outcomes in their export market. We examine consumer welfare and firm outcomes such as entry investments and sales. The exposition focuses on the key equilibrium conditions and the intuition for these in a single industry setting. In online Appendix D we provide details on the derivation of certain expressions and the multi-industry extension. We show that with limited information the model can be used to examine counterfactuals beyond the Chinese episode such as the impact of US TPU against all its trade partners. In Section IV we employ this structure and the estimated structural parameters to examine the implications for China's WTO accession.

A. *Setup*

These extra assumptions allow us to determine aggregate expenditure, E_s, and the price index, P_s:

- A1. There is no borrowing technology available across periods.
- A2. Individuals are either workers or entrepreneurs, with mass L and N, respectively. Entrepreneurs are endowed with a blueprint embodied in the marginal cost, c_v, and receive the profits of their variety and any lump-sum rebates of tariff revenues.
- A3. The period utility reflects a constant expenditure share on differentiated goods equal to $\mu > 0$ for workers and zero for entrepreneurs.
- A4. There are two countries with identical preferences.

Under these assumptions, TPU does not affect aggregate expenditures, which allows us to focus on the effects via the price index; the latter are important in our empirical setting and in understanding welfare effects for consumers. To see this we highlight the following implications. (i) A1 implies that current expenditures must equal current income each period for each individual. (ii) A2 implies that the only source of worker income is the wage, which is pinned down at unity—by the marginal product of labor in the numéraire—provided the population in each country is sufficiently large for the numéraire to be produced in equilibrium. (iii) The constant equilibrium wage and A1–A3 together imply that expenditure on differentiated goods is constant: $E_s = \mu L$ for all s; so the price index is the only aggregate endogenous variable that is uncertain in each country. (iv) The indirect utility for workers is $\tilde{\mu} P_s^{-\mu}$ in each state.[22] (v) A3 implies that entrepreneurs have linear utility so the entry decision of risk-neutral entrepreneurs is obtained by solving the Bellman

[22] The constant is $\tilde{\mu} \equiv w\ell\mu^{\mu}(1-\mu)^{(1-\mu)}$ where ℓ is the labor endowment and $w = 1$ in equilibrium.

equation defined in Section IB.[23] (vi) A4 rules out third country effects, mostly for expositional reasons.[24]

The price index for differentiated goods in state s depends on imported and home varieties, $\Omega_s = \Omega_{s,x} \cup \Omega_{s,h}$:

$$(14) \quad P_s^{1-\sigma} = \int_{\Omega_s} (p_{vs})^{1-\sigma}\, dv = \int_{\Omega_{s,x}} (\tau_m d c_v/\rho)^{1-\sigma}\, dv + \int_{\Omega_{s,h}} (c_v/\rho)^{1-\sigma}\, dv,$$

where $\rho \equiv (\sigma - 1)/\sigma$. Before deciding to enter, firms form rational expectations about the expected price index, P_s^e. In equilibrium $P_s^e = P_s$ given the following information structure. At the start of each period t a surviving firm knows its cost, c_v, and there is a common knowledge information set, denoted by $\mathbf{i}_s$, that includes: (i) the fixed exogenous parameters of the model including the survival rate and the time invariant set of potential varieties in each country, Ω; (ii) the structure of the model including the entry decision rules; (iii) the current realization of the policy; and (iv) the equilibrium set of varieties sold in each market in the previous period, denoted by Ω_{t-1}. The state, s, is defined by the combination of the realized policy at t and Ω_{t-1}.

We define the equilibrium as the following set of prices and quantities in each country and state s: (a) a demand vector for the differentiated and numéraire good, $\mathbf{q}_s$; (b) a market entry decision for each differentiated firm v and a distribution of active firms, Ω_s, with prices, $\mathbf{p}_s$; (c) an expected and actual price index, P_s^e and P_s; and (d) labor demands for the differentiated and numéraire goods and a wage, that satisfy the following conditions: (i) the numéraire good market clears; (ii) workers maximize utility subject to their budget constraint taking their factor endowments and all prices as given; (iii) entrepreneurs maximize utility subject to their budget constraint taking as given their factor endowment, technology, wage, P_s^e, the policy regime (Λ) and its lump-sum revenue, and all other information in $\mathbf{i}_s$; (iv) $P_s = P_s^e$ due to rational expectations (see online Appendix D); and (v) the labor market clears.

Since TPU now affects the price index there will be aggregate uncertainty and transition dynamics after policy shocks. We derive key analytical results for cutoffs, to compare with the partial effects, and for the price index, to compare with the literature on the aggregate gains from trade. We then provide a numerical solution for the model using exact changes.

B. *Equilibrium Entry, Prices, and Welfare*

We focus on exact changes, $\hat{y}_s \equiv y_s/y_b$—the ratio of some outcome y in state s and its baseline value. To fix ideas we choose a baseline with a deterministic

[23] Namely, equation (4) evaluated at a, K, β for the export decision to the home market and the same equation evaluated at a_{sh}, K_h, β_h for domestic production entry. We can interpret the exogenous discount factor in the Bellman equation as the survival probability of the entrepreneur or more generally the product of that probability and the probability of survival of the invested entry capital. We rule out the possibility that entrepreneurs are credit constrained by assuming that their endowment ℓ is always at least as high as the sunk entry investment so they can always self-finance this cost in a single period even if it exceeds that period's operating profits.

[24] If third countries don't face tariff shocks themselves in this market then they can be included since any shocks to their competitors' tariffs affect third-country firms only via the price index and so they react similarly to domestic firms.

policy $\tau = \tau_b$, so $y_b \equiv y(\tau_b, \gamma = 0)$. Using the demand expressions and (14) we rewrite the aggregate price change as a function of the price changes in imports, $P_{s,x}$, and domestic varieties $P_{s,h}$ —where $P_{s,i} \equiv \left[\int_{\Omega_{s,i}} (p_{vs})^{1-\sigma} dv\right]^{1/(1-\sigma)}$ for $i = x, h$, as follows:

$$(15) \qquad \left(\hat{P}_s\right)^{1-\sigma} = I\left(\hat{P}_{s,x}\right)^{1-\sigma} + (1-I)\left(\hat{P}_{s,h}\right)^{1-\sigma} \quad \text{for all } s.$$

The weight, $I \equiv \tau_b R_b / E_b$, is the share of expenditure on imports in the baseline, i.e., the import penetration ratio (online Appendix D.1.2).

Any firm with costs below the relevant cutoff in state s serves the market as do other surviving firms that previously entered under better conditions. Therefore, the varieties that determine each $P_{s,i}$ can reflect the entry cutoffs in that state and prior ones. The expression in (15) reflects this hysteresis due to sunk costs as does the quantification. The latter focuses mainly on comparing stationary equilibria and so does the exposition below. Stationary equilibria are characterized by a constant mass of active domestic and foreign firms in each market and thus constant price indices for any given τ_m. The stationary price index is then $P_m = P(c_m, c_m^h, \tau_m)$, which evaluates (14) at the cutoffs for each state.[25] Similarly, the domestic component of the price index is $P_{m,h} = P_h(c_m^h)$ so its change, $\hat{P}_{m,h}$, depends on changes in the domestic entry cutoff, $\hat{c}_{m,h}$. The import price index is $P_{m,x} = P_x(c_m, \tau_m)$ and therefore $\hat{P}_{m,x}$ depends on the change in the cutoff and also in tariffs if $\tau_m \neq \tau_b$.

The key analytical results do not rely on a specific productivity distribution but the estimation and quantification uses a Pareto, and in this case we obtain

$$(16) \qquad \left(\hat{P}_m\right)^{1-\sigma} = I(\hat{\tau}_m)^{1-\sigma}(\hat{c}_m)^{k-(\sigma-1)} + (1-I)\left(\hat{c}_{m,h}\right)^{k-(\sigma-1)} \quad \text{for all } m.$$

The equilibrium price change depends on entry changes for which we now solve.

Deterministic Policy Baseline.—If the policy is expected to remain at τ_m then the price index is $P_m^D \equiv P\left(c_m^D, c_{m,h}^D, \tau_m\right)$, which evaluates (14) using the available varieties. An exporting firm serves this market if its cost is below $c^D\left(P_m^D, \tau_m\right)$, as given in (3). A domestic firm serves the market if its cost is below $c_h^D\left(P_m^D\right) = \left[a_{mh}/((1-\beta_h)K_h)\right]^{\frac{1}{\sigma-1}}$.

Each firm's investment to serve a country is independent of the price index in another country.[26] We can then solve for the price, production, and export cutoffs by finding the unique solution to the three equations defining the equilibrium value of these variables in each country. In online Appendix D.1 we show that higher tariffs increase the equilibrium price index, $dP^D/d\tau > 0$, reduce export entry, $dc^D/d\tau < 0$, and increase domestic entry, $dc_h^D/d\tau > 0$. Replacing the equilibrium

[25] If $T \geq 0$ periods ago the tariff changed to τ_m then the stationary equilibrium is given by the value of $y_{T\to\infty}(\tau_m)$. In a stationary equilibrium there is still exogenous death but it is exactly offset by entry thus leaving the firm mass unchanged.

[26] The separability arises because the equilibrium wage is constant and the marginal domestic entrant pays the sunk cost after knowing its productivity and is assumed to be unproductive enough that it never exports.

cutoff changes into (16) we obtain the following price index change in any state m as a function of policy changes and baseline import penetration:

$$\hat{P}_m^D = \left[I(\hat{\tau}_m)^{1-\frac{\sigma k}{\sigma-1}} + (1-I)\right]^{-1/k} \quad \text{for all } m. \tag{17}$$

Consumer welfare changes in this model are given by $(\hat{P}_m^D)^{-\mu}$ and we can compare them to the cost of autarky, which is $\left[\hat{W}_m = (\hat{P}_m^D)^{-\mu}\right]_{\hat{\tau}_m \to \infty} = (1-I)^{\mu/k}$. Autarky is costlier, or equivalently the gains from trade with a given country larger, the higher the initial import share from that country, I, and the lower the trade cost elasticity, k. Thus, the expression for deterministic welfare gains from trade for consumers in our model is similar to those obtained in a broader class of static trade models (cf. Arkolakis et al. 2012).[27]

Uncertain Policy.—We now allow for three policy states. Switching out of the intermediate state occurs with probability γ and can worsen conditions for foreign firms (higher protection) or domestic ones (lower protection). Either switch leads to gradual exit and transition dynamics as the price index adjusts up toward its stationary value. So entry decisions will depend on the expected transition paths for economic conditions.

The export entry cutoff relative to the deterministic baseline, τ_b is $\hat{c}_1 \equiv c_1^U / c_b^D$, is still obtained by solving the optimal stopping problem in Section IB but now tariffs also affect the price index, P (online Appendix D.1.3):

$$\hat{c}_1 = U(\omega g, \gamma) \times \hat{P}_1 \times (\hat{\tau}_1)^{-\frac{\sigma}{\sigma-1}}; \tag{18}$$

$$U(\omega g, \gamma) \equiv \left[\frac{1 + u(\gamma)\,\omega g}{1 + u(\gamma)}\right]^{\frac{1}{\sigma-1}}. \tag{19}$$

The effect of uncertainty if we hold tariffs fixed is obtained by setting $\hat{\tau}_1 = 1$. We note two differences relative to the small exporter. First, there is a price change, captured by $\hat{P}_1$. Second, the average operating profits under the worst-case scenario relative to state 1 are now $\omega g = (\tau_2/\tau_1)^{-\sigma} g$, where

$$g \equiv (1-\beta) \sum_{T=0}^{\infty} \beta^T \left(\frac{P_{2,T}}{P_1}\right)^{\sigma-1}, \tag{20}$$

and $P_{2,T}/P_1$ is the relative price index T periods after switching to high protection. So g is the average change in profits due to aggregate price changes after a transition to high protection. With a small exporter $g = 1$, whereas now it will typically differ from unity. Our solution will show that this does not overturn the direct tariff effect, i.e., we continue to have $(\tau_2/\tau_1)^{-\sigma} g < 1$ and thus $U < 1$.[28]

[27] Equation (17) also applies to a model with multiple exporters to this market if they face deterministic tariffs and have the same distribution parameter, k. We use I equal to either the aggregate import share (complete autarky) or the import share of a specific country (partial autarky).

[28] So, conditional on the price index change, we continue to obtain the TPU-augmented gravity equation (10); the main difference is that the coefficient on τ_2/τ_1 reflects $u \times g$, whereas it reflected only u in the small exporter case.

Next we solve for the change in domestic entry. With sunk costs of domestic entry, $K_h > 0$, the domestic cutoff change, $\hat{c}_{1,h} \equiv c^U_{1,h}/c^D_{b,h}$ is

$$\hat{c}_{1,h} = U_h(g_h, \gamma) \times \hat{P}_1; \tag{21}$$

$$U_h(g_h, \gamma) \equiv \left[\frac{1 + u_h(\gamma)\, g_h}{1 + u_h(\gamma)}\right]^{\frac{1}{\sigma-1}}; \tag{22}$$

$$g_h \equiv (1 - \beta_h) \sum_{T=0}^{\infty} (\beta_h)^T \left(\frac{P_{0,T}}{P_1}\right)^{\sigma-1}. \tag{23}$$

The relevant domestic TPU factor is now U_h, which depresses domestic entry. The intuition is similar to export entry, except that the worst-case scenario for domestic firms is the low protection state. Starting in the intermediate state the expected duration of low protection is $u_h(\gamma) \equiv \gamma(1 - \lambda_2)\,\beta_h/(1 - \beta_h)$ and the expected change in profits after that transition, g_h. After a transition to low protection the domestic price index falls and thus so do domestic profits, hence $g_h < 1$.

Sunk costs generate transition dynamics after moving from the intermediate state. A switch to the low protection state triggers immediate entry of exporters and a lower price index; over time domestic firms die and fewer reenter due to the lower price index. Thus, the price index overshoots: it jumps down on impact and then increases along the transition (Figure A4). The switch to high protection increases the price index both on impact and gradually over the transition, as fewer exporters enter.

Replacing the export and domestic entry cutoffs into (16) we obtain the change in the stationary price index in the intermediate TPU state relative to the deterministic baseline:

$$\hat{P}_1 = \left[I(\hat{\tau}_1)^{1-\frac{\sigma k}{\sigma-1}}(U)^{k-(\sigma-1)} + (1 - I)\,(U_h)^{k-(\sigma-1)}\right]^{-1/k}. \tag{24}$$

When $U = U_h = 1$ we obtain the deterministic expression in (17). The price change due to TPU alone, if $\hat{\tau}_1 = 1$, increases the price index due to its effect on foreign firms, $U < 1$, and domestic ones, $U_h < 1$. Therefore, the intermediate TPU equilibrium must contain fewer foreign firms, fewer domestic firms, or both.

The general equilibrium entry effects are perhaps less obvious. TPU has a direct negative effect on foreign and domestic entry, which pushes up the price index; so the net impact of TPU is to lower entry if the direct uncertainty effect is sufficiently strong. These opposing effects may imply that foreign and domestic entry move in opposite directions. If the intermediate tariff, τ_1, is very close to its low protection value, τ_0, then TPU increases domestic and lowers foreign entry. This will be the case in our application to China and occurs because the domestic firms were already close to their worst-case scenario of low protection. Conversely, if τ_1 were close to τ_2, then there would be more foreign entry under TPU and less domestic entry.

In sum, the general equilibrium analysis will allow us to quantify key effects and highlights qualitatively novel implications of TPU. Notably, TPU can reduce domestic entry, which is not possible in a similar setting with a deterministic tariff.

Moreover, when this domestic entry reduction is sufficiently large it implies that consumer welfare is below the permanent autarky level, as one of our counterfactual exercises shows.

C. *Solution*

To characterize and quantify the effects of TPU, we solve a multi-industry version of the model for the complete sequence of prices and entry decisions. We describe the key elements and solution approach here.

Inputs: The model and its solution require:

- a set of exogenous parameters: $\Theta \equiv \{k, \sigma, \Lambda(\tau_m, \gamma), \beta, \beta_h\}$;
- baseline equilibrium import shares: $\mathbf{I} \equiv \{I_V(\tau_b, \gamma = 0)\}$, where $I(\tau_b, \gamma = 0) = \Sigma_V I_V(\tau_b, \gamma = 0)$.

Equilibrium: The entry conditions (18) and (21) and U, U_h yield a system of equations for:

- the relative stationary price index in the intermediate state, $\hat{P}_1(g, g_h, \Theta, \mathbf{I})$ in (24);
- the sequence of relative prices after a switch to low or high protection, respectively $\hat{P}_{0,T}(g_h, \hat{P}_1, \Theta, \mathbf{I})$, in (20) and $\hat{P}_{2,T}(g, \hat{P}_1, \Theta, \mathbf{I})$, (45) in online Appendix D.1.2;
- the average profit change due to prices after a switch to high or low protection, respectively $g(\hat{P}_{2,T}/\hat{P}_1, \Theta)$ in (20) and $g_h(\hat{P}_{0,T}/\hat{P}_1, \Theta)$ in (23), where $\hat{P}_{.}$ denotes a price index relative to the baseline, e.g., $\hat{P}_{2,T} \equiv P_{2,T}/P_b$.

Solution: $\Upsilon(\Theta, \mathbf{I}) \equiv \{\hat{P}_1; g; g_h; (\hat{P}_{2,T}; \hat{P}_{0,T})_{T=0}^{\infty}\}$ is found by:

- fixing a set Θ consistent with our estimation and data I;
- iterating n times until we obtain a fixed point such that $\Upsilon^{(n)}(\Theta, \mathbf{I}) = \Upsilon^{(n-1)}(\Theta, \mathbf{I})$.

To understand the approach, recall that entry requires firms to incorporate expected changes in profits caused by tariffs and prices. To solve for prices starting in state 1, the solution algorithm uses the upper bounds $g^{(0)} = (P_2^D / P_1^D)^{\sigma-1}$ and $g_h^{(0)} = (P_0^D/P_1^D)^{\sigma-1}$, which we compute using the deterministic equation in (17). Using these we compute the initial values for $\hat{P}_1$ and the paths $(\hat{P}_{2,T}; \hat{P}_{0,T})_{T=0}^{\infty}$, which are then used to update g and g_h. We iterate until the g's and thus the other elements of the solution converge.

We use the following inputs. First, we choose 2005, a post-agreement year, as the baseline and use it to measure the import expenditure shares, I_V, and tariffs, τ_{0V}. Second, we require values for Θ; the elasticities can be estimated (as we show below); β and β_h are obtained from annual export and domestic firm survival rates data. The tariffs for each of the three states are observable in the China episode (τ_{1V} is the 2000 MFN and τ_{2V} the column 2); we use these unless stated otherwise for specific counterfactual exercises.

To solve the model we also require the expected durations embodied in u and u_h. One contribution of this paper is to identify these parameters and quantify the role of TPU in China's WTO accession, which we do in Section IV. But first we analyze the model's behavior under alternative parameters.

D. *Outcomes and Policy Experiments*

We solve the model under alternative policy regimes to explain its key mechanisms and illustrate its applicability to a range of trade policy questions. The main counterfactual is one where the United States unilaterally abandons its trade agreement commitments against all its trading partners and adopts a regime similar to the one it used for China prior to 2002. This is a potentially useful benchmark to illustrate the qualitative effects of TPU and is also not implausible under the forty-fifth US president.[29]

We allow for alternative policy regimes as follows. Recall that $u \equiv \gamma \lambda_2 \beta/(1-\beta)$ and $u_h \equiv \gamma(1-\lambda_2)\beta_h/(1-\beta_h)$. To focus on the uncertainty parameter we use $\lambda_2 = 1/2$, so high and low protection are equally likely and then solve the model under all possible $\gamma \in [0,1]$. The policies τ_{0V}, τ_{1V}, and τ_{2V} are set equal to their simple means when computing $\hat{\tau}_1$ and $\hat{\tau}_2$, which implies we only require aggregate import penetration.[30] The remaining parameters are given in Table A11. We proceed in three steps:

(i) Evaluate the effects of switching policy states within a regime, e.g., a transition to the low protection state, and decomposing them into a TPU and an applied policy component.

(ii) Perform counterfactual analysis of switching policy regimes, e.g., the effects of introducing TPU under different applied or threat policies.

(iii) Calculate gains from trade under TPU and draw implications for trade agreements.

Effects of Switching Policy States.—The total change in the stationary price index between state 1 and 0, where we interpret the latter as an agreement, can be decomposed into a TPU and applied policy change as follows:

$$\hat{P}_1 \equiv \frac{P_1}{P_0^D} = \underbrace{\left(\frac{P_1}{P_1^D}\right)}_{\text{TPU}} \times \underbrace{\left(\frac{P_1^D}{P_0^D}\right)}_{\text{Applied } \hat{\tau}_1}. \tag{25}$$

To obtain the TPU component we solve the model for $\hat{P}_1$, at each possible γ, and then divide it by the applied policy component, $P_1^D/P_0^D = \hat{P}_1^D$ computed from (17).

[29] For any given set of parameters, the qualitative impacts of TPU are similar to those we later obtain for China alone. But since aggregate import penetration is larger when introducing TPU on all partners (0.25 in 2005), it typically generates stronger aggregate impacts on the United States.

[30] In the application to China (Section IV) we use: (i) specific parameters implied by the estimation; (ii) $\hat{\tau}_{1V}$ and $\hat{\tau}_{2V}$ as the ratio of the 2000 MFN and column 2 tariffs, respectively, to the 2005 MFN tariffs in each industry V; and (iii) Chinese import penetration in each industry V.

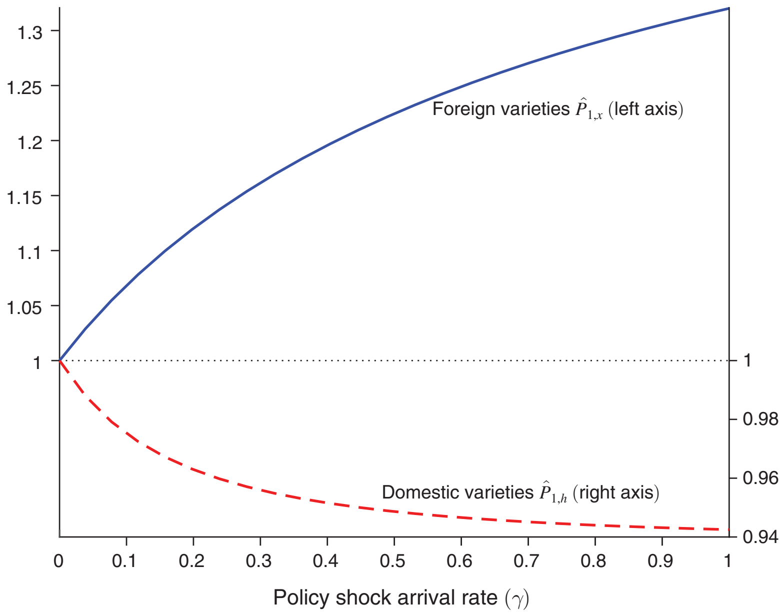

FIGURE 5. DOMESTIC AND FOREIGN VARIETY PRICE INDICES (*Counterfactual Introduction of US TPU on All Partners*)

Notes: General equilibrium solution of the model for each variable's growth relative to deterministic baseline if the United States introduces TPU in 2005. Solutions computed from estimated and other parameters in Table A11.

We can decompose the impact of TPU on entry and all other variables similarly. The tariffs in 2005 and 2000 were very similar so $\hat{\tau}_1$ and thus $\hat{P}_1^D$ are close to 1. Therefore, in Figures 5 and in the first column of Figure 6 we graph the TPU component for different outcomes against all possible γ.

Aggregate price index increases by as much as 5 percent if $\gamma = 1$ with almost one-half occurring even at moderate uncertainty, $\gamma = 0.25$ (panel A).

Foreign sales and entry fall by as much as 35 percent (sales) and 60 percent (entry) if $\gamma = 1$. Even moderate uncertainty generates a considerable reduction in entry, 40 percent (panel D).

Domestic sales and entry sales increase by up to 12 percent if $\gamma = 1$. Entry is only initially increasing in TPU but at sufficiently high γ the direct effect of TPU, U_h, starts to offset the indirect price effect (panel G).

We break the price index change into its foreign and domestic components in Figure 5. The decline in foreign variety entry due to TPU causes the foreign component to increase by as much as 30 percent. This large change is partly offset in the aggregate price index by the decline in the price index of domestic varieties.

Effects of Switching Policy Regimes.—Different events can trigger a change in γ without any change in a state or tariff values. For example, in the years leading up to WTO accession Chinese exporters may have changed their assessment about the probability of that outcome. Alternatively, if the United States abandoned its trade agreements but left its tariffs unchanged then we could examine it as a change in γ. The graphs just described also allow us to evaluate such counterfactuals by simply taking the ratio of the outcomes at different γ since $\hat{P}_1(\gamma')/\hat{P}_1(\gamma) = P_1(\gamma')/P_1(\gamma)$.

An alternative counterfactual regime is one with different threat tariffs. To examine this we continue to fix $\tau_1 = 1.04$ and now also fix $\gamma = 0.25$ and then compute $\hat{P}_1$ and $\hat{P}_1^D$ by solving the model at all alternative counterfactual values of τ_2. We allow $\tau_2 \in [1.04, 1.38]$ so it ranges from τ_1 to the maximum value of τ_2 in our sample. We obtain the TPU component for prices using (25) and do the same for the other outcomes.

The middle column of Figure 6 shows that TPU has the strongest effects on entry and sales at the highest threat tariff. Reductions in τ_2 have opposing effects on domestic and foreign entry and thus on their respective price indices. But the import price index effect always dominates; as reflected in the monotonically increasing effect of TPU on the aggregate price as we raise τ_2. At the highest τ_2 introducing TPU implies an increase in the price index that is about one-third of what would result if the United States reverted to autarky. The autarky cost is shown by the straight line and is computed using (17).

Finally, we consider the impact of TPU under alternative applied tariffs, e.g., if the United States did abandon its trade commitments and reverted to a temporary tariff above the 2000 MFN level. We fix τ_2 and γ and solve the model for $\tau_1 \in [\tau_0, \tau_2]$. The results in the last column of Figure 6 reflect two effects of increasing τ_1. First, at higher τ_1 the import penetration on which TPU acts is lower. Second, higher τ_1 implies a relative decrease in the threat for foreign varieties and the opposite for domestic varieties. Introducing TPU can reduce both foreign and domestic entry at high enough tariffs, as shown in the last column of Figure 6 and summarized here.

Aggregate price index is higher under TPU at all τ_1 (panel C).

Foreign sales and entry both fall with TPU when τ_1 is close to τ_0 (as seen before) since the possibility of high protection implies a substantial tariff increase. This negative effect of TPU is reversed when τ_1 approaches τ_2. At that point foreign exporters have little to lose if the policy switches to τ_2 and thus the direct price effect (due to lower entry of domestic firms) dominates (panel F).

Domestic sales and entry both increase with TPU when τ_1 is close to τ_0 (as seen before). But if τ_1 is above 1.1 then TPU reduces entry because the direct effect, from lower U_h, eventually offsets the indirect price effect. At high enough τ_1, TPU reduces domestic sales (panel I).

In this exercise, the long-run mean is $\overline{\tau}_1 = \lambda_2 \tau_2 + (1 - \lambda_2)\tau_0 = 1.21$ so introducing TPU at that point is a mean-preserving spread of the policy. Therefore the outcomes in the last column of Figure 6 evaluated at that tariff level show the pure risk effect of TPU, which leads to lower entry: both foreign and domestic. In Section IVA we extend this approach to decompose the effects of TPU on China into a pure risk and mean effect.

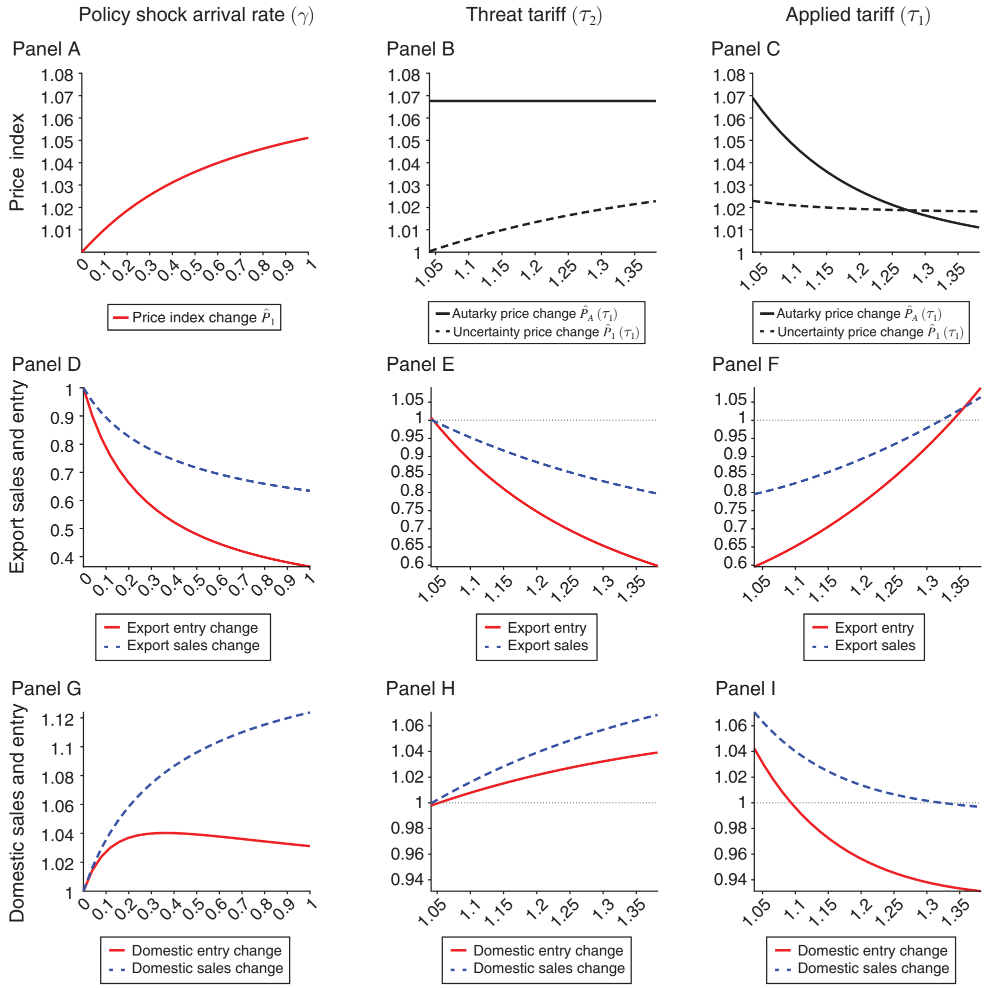

FIGURE 6. AGGREGATE PRICE, SALES, ENTRY (*Counterfactual Introduction of US TPU on All Partners*)

Notes: Model solution for a variable's growth relative to deterministic baseline if the United States introduces TPU in 2005 using parameters in Table A11. For panels B, E, and H, the threat tariff (τ_2) ranges from the mean observed MFN tariff of 1.041 to the column 2 tariffs of 1.38, both in 2000. For panels C, F, and I, the applied tariff (τ_1) ranges from the simple mean of the observed MFN tariff in 2005 of 1.038 to the column 2 tariffs in 2000 of 1.38. Aggregate import weights and import penetration are adjusted for the counterfactual τ_1 relative to observed values in 2005. For B the price change from increasing uncertainty or autarky is computed relative to a fixed applied $\tau_1 = 1.041$. For C the autarky price change is computed over $\tau_1 \in [1.038; 1.38]$.

Gains from Trade, Value of Agreements, and Tariff Bindings.—What are the implications of these results for the value of trade agreements and some of their key features?

An immediate implication is that if agreements reduce TPU then they increase consumer welfare via aggregate price reductions. How important are these price effects of TPU relative to say imposing prohibitive tariffs? This depends on the policy regime. At the baseline value of τ_1 autarky generates a price increase of about 6.8 percent; the effect of TPU is one-third of that when $\gamma = 0.25$ and two-thirds if

$\gamma = 1$ (panel A of Figure 6). This suggests an important value of agreements that eliminate such uncertainty.[31]

Can the cost of TPU ever exceed that of autarky? In the last column of Figure 6 we see that it may, depending on the initial tariff. The price effect of autarky, $\left(\hat{P}_m^D\right)_{\hat{\tau}_m \to \infty} = \left(1 - I_{\tau_1}\right)^{-1/k}$, is decreasing in τ_1 because at higher tariffs there is lower import penetration and thus a lower cost of eliminating trade. At high enough τ_1 the cost of TPU is higher than that of autarky because TPU reduces domestic entry by so much that it eventually leads to less entry than autarky.

The possibility that TPU is costlier than autarky relies on TPU reducing domestic entry. In this exercise that occurs above $\tau_1 = 1.1$. During most of the GATT era the US simple average tariff has been below 1.1, but it was around 1.22 immediately preceding GATT, in 1947 (Bown and Irwin 2015). So if GATT 1947 reduced the probability of a trade war, which was one of its objectives, then the model suggests it may have increased both foreign and domestic entry investments and realized a large fraction of the possible gains from trade (since at $\tau_1 = 1.22$ the price effect of TPU is close to that of autarky).

Our counterfactual results can also provide support for the central role of tariff bindings in the WTO. Countries negotiate maximum tariffs in the WTO and commit not to exceed those bindings but are otherwise free to set their applied tariffs. We can reinterpret γ as the probability of changing tariffs anywhere below the binding and τ_2 as the potential maximum levels and examine the effect of changes in the latter.[32] By 2005 the US applied and tariff bindings were almost the same, so this would match the outcome when $\tau_2 = \tau_1$ in the middle column of Figure 6, where we see that increasing that binding decreases welfare and trade.

In sum, this section illustrates how the model works qualitatively, how it can be applied more broadly and indicates there is an important role for trade agreements. We now turn to a specific episode where we can estimate the uncertainty parameters and quantify the effect of an agreement.

IV. Structural Estimates and Quantification

NLLS Structural Estimates.—We identify the key structural parameters to quantify the effects of TPU via nonlinear estimation. This approach differs from Section II in two ways. First, the gravity equation is still (10) but the uncertainty factor, $U(\omega_V g, \gamma)$, now reflects a general equilibrium factor common to all industries. Second, we now use $f(\cdot) = -(k - \sigma + 1)\ln U(\omega_V g, \gamma)$ and the exact definition of U instead of an approximation around no uncertainty to rewrite (11) and obtain

$$(26) \quad \Delta \ln R_V = b_{d\sigma} \ln \left[\frac{1 + \tilde{b}_\gamma \left(\frac{\tau_{2V}}{\tau_{1V}}\right)^{-b_\sigma}}{1 + \tilde{b}_\gamma / g} \right] + b_\tau \Delta \ln \tau_V + b_d \Delta \ln D_V + b + e_V.$$

[31] In our setting, the welfare effects for US consumers would be similar if other countries retaliated and introduced uncertainty on US exporters (the latter would then have lower profits). This is due to the separability of markets, fixed wage and the assumption that the marginal domestic entrant knows its productivity and is not an exporter.

[32] We can reinterpret the model as corresponding to three different states between members of the WTO: in state 1 countries have discretion to set tariffs anywhere at or below the binding, τ_2, and a probability $\gamma\lambda_2$ they will use the discretion and set τ_2; state 0 corresponds to giving up any such discretion.

TABLE 6—CHINESE EXPORT GROWTH: NONLINEAR AND LINEAR ESTIMATES (*US*, Δln), 2000–2005

	NLLS (1)	OLS (2)	NLLS (3)	OLS (4)
Uncertainty (pre-WTO)	0.903	0.686	0.712	0.567
[+]	[0.324]	[0.150]	[0.345]	[0.185]
MFN tariff (Δln)	−6.678	−6.464	−6.446	−6.34
[−]	[1.26]	[1.266]	[1.268]	[1.270]
Transport cost (Δln)	−4.452	−4.309	−4.298	−4.227
[−]	[0.84]	[0.844]	[0.845]	[0.847]
Constant	1.598	0.877		
	[0.109]	[0.0845]		
Observations	3,043	3,043	3,043	3,043
R^2	0.02	.	0.04	.
Sector fixed effects	No	No	Yes	Yes
Number of coefficients estimated	3	3	23	23
Restriction test $\sigma = 3$ (p-value)	0.11	NA	0.98	NA
Restriction test $b_\tau = b_d \times \sigma/(\sigma - 1)$ (p-value)	0.335	0.373	0.72	0.818

Notes: Standard errors in brackets. Columns 1 and 3 use nonlinear least squares and columns 2 and 4 use ordinary least squares. Predicted sign of coefficient in brackets under variable. Sample: all specifications exclude transport cost outliers, as measured by changes in costs that exceed the top or bottom quartile by more than three times the value of the interquartile range. Uncertainty measure uses US MFN (τ_1) and column 2 tariffs (τ_2) to construct the profit loss measure. This is approximated by $1 - (\tau_1/\tau_2)^\sigma$ under OLS. For NLLS we do not approximate and use instead the general function $\ln(1 + b_\gamma \times (\tau_1/\tau_2)^\sigma)$ where b_γ is estimated as described in the text. The four specifications in the columns restrict $\sigma = 3$. We test this by relaxing the restriction in two additional NLLS specifications; we report the p-values in the second to last line at which we can't reject the restriction. We also impose the restriction that $b_\tau = b_d \times \sigma/(\sigma - 1)$. The last row reports p-values from the test of this restriction.

The parameters have the following structural interpretation: $b_d = -k$ and $b_\tau = -k\sigma/(\sigma - 1)$, $\tilde{b}_\gamma = u(\gamma)\, g$, $b_\sigma = \sigma$, and $b_{d\sigma} = -(k - \sigma + 1)/(\sigma - 1)$. One component of U, $1 + \tilde{b}_\gamma/g = 1 + u$, is log-separable and does not vary by industry so we cannot identify it separately from the constant, b. The nonlinear least squares (NLLS) regression yields estimates for $\tilde{b}_\gamma$, b_d, and b. We impose two theoretical restrictions: $b_{d\sigma} = \left((b_d + b_\sigma - 1)\right)/(b_\sigma - 1)$ and $b_\tau = b_d b_\sigma/(b_\sigma - 1)$; as before we impose $b_\sigma = 3$ but we will now test it.

Column 1 of Table 6 provides the NLLS estimates. For comparison with earlier results, we transform the estimate for $\tilde{b}_\gamma = 0.736$ into its OLS regression counterpart, $b_\gamma^{nlls} = \tilde{b}_\gamma(-b_d - b_\sigma + 1)/(b_\sigma - 1) = 0.90$. The point estimates are comparable to the OLS counterpart (column 2) and similar when we control for sector effects (columns 3 and 4). But below we show the partial equilibrium OLS estimates overestimate the trade effects.[33]

[33] Given that the NLLS estimation relies on the model structure and the variation in the transport cost variable to identify k, we minimize the potential influence of outliers by focusing on the subsample without transport cost outliers, as measured by changes in costs more than three times the interquartile range value beyond the top or bottom quartile value of the baseline sample. The estimate for k in this subsample is higher (under NLLS or OLS) than the baseline, which suggests that the transport cost for some products contained measurement error and generated attenuation bias.

Consistency with Model and Other Evidence.—Before using these estimates, we ask whether they are consistent with the model and other evidence. The signs of all estimated parameters are those predicted by the model. We also run the NLLS baseline specifications by individually relaxing $b_\tau = b_d \sigma/(\sigma - 1)$ or $b_\sigma = 3$. We fail to reject either of these restrictions and report p-values in the last two rows of Table 6. Our choice of $\sigma = 3$ is typical in trade estimates and the partial elasticity of exports to tariffs in the absence of uncertainty, -6.6, is close to previous estimates that use similarly disaggregated US trade and tariff data (cf. Romalis 2007).

Under a Pareto productivity distribution with shape parameter k, export sales without uncertainty are also Pareto but with shape $k/(\sigma - 1)$. The 95 percent confidence interval for our estimate of the sales distribution parameter is $b_d/(\sigma - 1)$ is $[1.4, 3.1]$. The estimate is larger than 1 and it satisfies the model's requirement for a finite first moment of sales, which we did not impose. The magnitude is similar to that in other studies using firm-level data.[34]

The other parameter central to the quantification is u: a Chinese exporter's expected duration of a spell under column 2 prior to WTO accession. This reflects the exporters' beliefs for an event that never occurred so we can't defend any particular value. Nevertheless, the bounds on our estimate are reasonable and consistent with the model. To fix ideas, consider a Chinese firm that starts exporting in 2000. Since firm-level studies suggest an expected export duration of between 6 and 7 years, our estimate implies that those firms expected to spend at least 10 percent of their exporting spell under column 2.[35]

We also estimate the probability of transitioning from state 1 to 2, given by $\lambda_{12} = \gamma\lambda_2$. Using the definition of $\tilde{b}_\gamma$ and u we obtain the estimate $\hat{\lambda}_{12} = \hat{u}(1 - \beta)/\beta$. The estimation does not restrict this parameter and yet we still find that it is bounded in the unit interval for reasonable annual probabilities of firm survival, β. The point estimate using the value for β employed in the general equilibrium derivation, is $\hat{\lambda}_{12} = 0.13$.[36]

In the presence of endogenous domestic firm entry we require those firms' beliefs of the expected duration of an agreement, u_h, for quantification. We are unable to identify this parameter empirically using US firm entry or sales data because the relevant uncertainty factor, U_h, does not vary across industries (all the tariff effects work through the price index). Therefore, we parametrize u_h by defining $\alpha \equiv u_h/u$. We choose $\alpha = 4$ as the central value, which implies that before the agreement, a US firm expected to spend 4 times as long under the WTO state than a Chinese exporter expected to spend under column 2. In Section IVA, we show that the quantification results are not very sensitive to alternative feasible values of α.[37,38]

[34] Eaton, Kortum, and Kramarz (2011) obtain an aggregate estimate of 2.46 using French exports; Hsieh and Ossa (2016) obtain a range from 1 to 1.44 over industries using Chinese firm data.

[35] The exit rate for new Chinese exporters is 0.16, implying a survival of 6.25 years (Ma, Tang, and Zhang 2014); our quantification employs $1 - \beta = 0.15$.

[36] When $\hat{u} = 0.73$ then $\hat{\lambda}_{12} = 0.73\frac{1-\beta}{\beta} \in (0,1]$ if $\beta \in [0.42, 1)$.

[37] Our estimate of $\gamma\lambda_2 = 0.13$ implies that $\lambda_2 \in [0.13, 1]$ and so, after applying the discount factor values, the range consistent with the estimates is $\alpha \in [0, 12]$, for which we report sensitivity. For the central case, $\alpha = 4$, we obtain $\lambda_2 = 0.28$.

[38] We also solved a special case of the model without domestic entry costs, so there is a constant mass of active domestic producers, which is independent of u_h. We find similar export value effects, and the effects for the

A final cross-validation of the NLLS estimates is to ask if the implied uncertainty measure, $\hat{U}_V$, can predict the observed industry price index changes exactly as predicted by (12) in Section IIF. Recall that we found larger price reductions in industries with higher initial TPU by using a linear approximation to U_V. Our objective here is to test a more specific structural implication of the model. We regress the observed changes in prices on tariff and trade cost changes and on $\left(k/(\sigma-1)-1\right)\left(-\ln U_V\right)$, where the latter is constructed using the NLLS estimates obtained using the export data. The uncertainty measure thus constructed is predicted to have a coefficient of -1 on price changes and we estimate it to be -0.96 (SE 0.21). Thus, the estimates from the export equation predict the effect of TPU on prices well.

A. *Quantification: Exports*

We quantify the effects of TPU changes, decompose them into a pure risk and mean effect, perform different counterfactual experiments and provide an ad valorem tariff equivalent cost of TPU. Table A11 summarizes the parameters we use based on our estimates and auxiliary data.

We quantify the effect of reintroducing uncertainty in 2005 on Chinese exporters. Qualitatively, the outcomes for Chinese varieties are similar to Section IIID but there are two differences worth noting. First, export entry and sales reflect the response of Chinese varieties whereas the *domestic entry* and sales reflect both US and other non-Chinese varieties.[39] Second, we now account for variation in policy across industries. The main quantitative difference is that in Section IIID we did not have the uncertainty parameters and so described a range of TPU impacts. We can now use our estimates for China to pinpoint a particular value for each outcome. We now contrast these GE point estimates to the partial effect estimates and place them into perspective relative to the observed changes during this period.

In the discussion that follows, we quantify the effect of reintroducing TPU in 2005, e.g., R_1/R_1^D for exports, and interpret its inverse as the impact of TPU reduction. We present all results using log changes.

Average Effects: General versus Partial.—The average log change from increasing TPU is given by

$$\mathbb{E}_V \ln R_{1V}/R_{1V}^D = \mathbb{E}_V \ln\left(U_V\right)^{k-(\sigma-1)} + k \ln P_1/P_1^D. \tag{27}$$

aggregate price index are only somewhat stronger than under endogenous domestic entry (because the absence of a domestic extensive margin is partially offset by a larger intensive margin impact).

[39] The US firms respond to the general equilibrium price index changes, as they did in the two-country model, but so do any other non-Chinese firms that face constant trade barriers in the United States. It is simple to show that, because we are solving for changes, this is the outcome from extending the model to multiple countries as long as all non-Chinese firms face a common σ and k, as is typical in this type of model, and a similar expectation of the duration of the low protection state, u_h.

Table 7—Impact of TPU Reduction on Chinese Export Value and Price (US, $100 \times \Delta\ln$), 2000–2005

	Policy uncertainty reduction estimates					
	Partial effect		General equilibrium effect		Data equivalent	
	Average	Aggregate	Average	Aggregate	Average	Aggregate
Export value	36	40	28	32	112	73.0
Export price	−15.2	−17.2	−14.8	−17	−26	−13

Notes: The first four columns are the model estimates for the growth in Chinese export value (or price) due to TPU reduction. The general equilibrium employs the coefficients from NLLS export estimates in column 1 of Table 6 and uses the model to incorporate the price index effects. The partial effect estimates ignore the price index effect and use OLS estimates for exports (column 2 of Table 6) and prices (column 1 of Table 4). The data equivalents for exports use the observed Chinese export growth (average or aggregate) and subtract nominal growth in the aggregate US expenditure on manufactures to account for nominal effects and aggregate expenditure shocks, which are held constant in the model prediction. The price growth data equivalent uses the average from Table 1 (or its aggregate using ideal weights) and subtracts the corresponding average (or aggregate) for non-Chinese varieties (used in Table A9) to account for common nominal shocks. The difference in the price data equivalent is mostly driven by the Chinese differential average and aggregate price growth.

The direct effect is -30 log points and the price index effect is 2 log points. Therefore the model implies that the reduction in TPU in the period 2000–2005 led to an average export increase of 28 log points, as shown in Table 7.[40]

We can contrast this with the partial effect from the linear estimation. The latter assumes no price effects and a linear approximation to U so the estimated partial effect counterpart to (27) is simply $-b_{\gamma}^{OLS} \times \mathbb{E}_V\big(1 - (\tau_{2V}/\tau_{1V})^{-3}\big) = -36$ log points. Thus, the implied partial effect on exports due to a TPU reduction is more than 20 percent higher than the GE effect. All subsequent exercises focus on the GE nonlinear estimates.

Aggregate Effects.—We now turn to aggregate effects of TPU for exports. The direct uncertainty effect, $-\ln(U_V)^{k-(\sigma-1)}$, ranges from about 0 to 57 log points and there is also considerable dispersion in export shares. So we weight each uncertainty factor by the relevant expenditure share to compute the growth of total expenditure on Chinese goods due to TPU. The aggregate effect is 32 log points, so higher than the average one;[41]

$$\ln R_1/R_1^D = \ln \sum_V r_{1V}^D (U_V)^{k-(\sigma-1)} + k \ln P_1/P_1^D. \tag{28}$$

The quantification implies that TPU can account for over one-third of observed changes on expenditure in Chinese goods. The counterfactual holds income and

[40] We compute $(U_V)^{k-(\sigma-1)}$ using the estimates in column 1 of Table 6, the implied $\hat{u} = 0.73$, and each τ_{1V}/τ_{2V}. The price effect term uses the multi-industry version of (24) at fixed tariffs and the decomposition given in (25). The effect is not sensitive to alternative values of α, it ranges from 29 to 30 log points if $\alpha = 6$ or 0 respectively.

[41] The appropriate weight to evaluate the TPU component is the import share at τ_1 that would have been observed if $\gamma = 0$, $r_{1V}^D \equiv \tau_{1V} R_{1V}^D / \Sigma \tau_{1V} R_{1V}^D$. Since these are not observed we compute them by using the observed initial equilibrium imports, R_{0V}^D, the model implied deterministic change due to tariff changes, $\hat{\tau}_{1V}$, and the estimated tariff elasticity, b_{τ}. Thus, we obtain $r_{1V}^D = \tau_{1V} R_{0V}^D (\hat{\tau}_{1V})^{b_\tau} / \Sigma \tau_{1V} R_{0V}^D (\hat{\tau}_{1V})^{b_\tau}$ since the aggregate effects cancel out.

aggregate US expenditure on differentiated goods constant, so it also applies to the growth in the share of US tradables expenditure on Chinese goods, i.e., the growth in Chinese import penetration. In Table 7 we report this share increased by 73 log points so TPU can account for over one-third of that growth.

For any given level of aggregate expenditure, the effect of TPU on import penetration growth is the same as its effect on imports. So introducing TPU in 2005 would reduce penetration from 4.5 percent to 3.3 percent. The effect of TPU can depend on the baseline year's expenditure share, which may vary for exogenous reasons. Thus, we calculate the TPU effect on import penetration for each year after the agreement as the baseline and plot them in Figure 1. The solid line shows the observed import penetration, which tripled between 2000 and 2010. The dashed line is the GE counterfactual showing that penetration would only have doubled if TPU had remained.

Mean-Risk Decomposition.—In Section IIID, we describe how to decompose the effect of an agreement into a change in applied policies and TPU. The latter TPU effect can be further decomposed into changes in the mean versus changes in risk. To show this, we rewrite the impact of a change in γ evaluated at the pre-agreement applied tariff level, τ_{1V} as

$$(29) \quad \ln\frac{R_V(\gamma_0,\tau_{1V})}{R_V(\gamma_1,\tau_{1V})} = \ln\frac{R_V(\gamma_0,\overline{\tau}_V)}{R_V(\gamma_1,\overline{\tau}_V)} + \left[\ln\frac{R_V(\gamma_0,\tau_{1V})}{R_V(\gamma_0,\overline{\tau}_V)} - \ln\frac{R_V(\gamma_1,\tau_{1V})}{R_V(\gamma_1,\overline{\tau}_V)}\right].$$

The first term on the right is the growth in exports due to credibly securing tariffs at their long-run expected value, denoted by $\overline{\tau}_V$, a reduction in γ will then work as a mean-preserving compression in tariffs, which we label the risk effect. If $\tau_{1V} < \overline{\tau}_V$ then eliminating uncertainty reduces the expected value of tariffs and this lock-in effect is captured by the term in brackets, which is positive when the initial tariffs are below the long-run mean, as is the case in our application.

To quantify the risk effect we require the counterfactual long-run tariffs, $\overline{\tau}_V$. Prior to the agreement these are $\overline{\tau}_V = \lambda_2\tau_{2V} + (1-\lambda_2)\,\tau_{0V}$ and can be computed using an estimate of λ_2 and the observed values for τ_{2V} and τ_{0V}. In Section IIID, we showed that the TPU effect can be computed at any counterfactual τ_1, so setting $\tau_1 = \overline{\tau}_V$ we compute $\ln[R_V(\gamma_0,\overline{\tau}_V)/R_V(\gamma_1,\overline{\tau}_V)]$ by industry. We then aggregate these changes, using the expenditure weights evaluated at $\overline{\tau}_V$. This yields a risk effect of TPU for exports equal to 23 log points, which is 71 percent of the total. The substantial share due to risk arises because even if we start at the higher mean tariffs the threat of moving to τ_2 entails a doubling of tariffs on average.

Ad Valorem Equivalents: TPU versus Applied Policies.—To compare the effects of TPU with other policies, we calculate ad valorem tariff equivalents (AVE) of TPU on exports and other outcomes. The AVE is defined as the deterministic log change in the uniform tariff factor, $\ln\Delta_y$, that generates the same change in an outcome y as TPU. Formally, Δ_y solves

$$(30) \quad y(\tau_1\Delta_y, \gamma = 0) = y(\tau_1, \gamma > 0).$$

Table 8—Impact on Chinese and US Outcomes of TPU Reduction and Corresponding Tariff Ad Valorem Equivalent (100 × Δln), 2000–2005

	AVE (tariff equivalent)	Aggregate change
Chinese (real) export value [−]	5.0	32.4
Chinese export entry and investment [−]	9.4	61.2
Chinese export price index [+]	6.1	−16.9
US price index (manufacturing) [+]	13	−0.5
US consumer welfare [−]	13	−0.4
US (real) domestic sales (manufacturing) [+]	5.9	−1.3
US domestic employment (manufacturing) [+]	7.3	−1.2
US firm entry and investment (manufacturing) [+]	1.8	−0.4

Notes: Quantification uses NLLS estimates (column 1, Table 6). AVE (ad valorem equivalent) refers to the equivalent tariff reduction that would induce the same change in outcome *x* in the deterministic model with no uncertainty as the TPU reduction does. See text for details of calculation. Equivalents for outcome *x* in any period after uncertainty changes but applied policies remain unchanged. Reported values reflect differences in steady-state outcomes between policy states. [−/+] denotes sign of derivative of column variables with regard to tariff.

If we divide both sides by the baseline value for exports $R(\tau_1, \gamma = 0)$ then the expression on the right-hand side yields the 32 log point change previously derived. The left-hand side will then reflect the change in exports due to a deterministic tariff change, both the direct and indirect effect via prices. Solving for the AVE we obtain $\ln \Delta_R = 5$ log points (Table 8). So the export AVE was higher than the US applied average tariff in 2000.

B. *Quantification: Entry, Prices, and Welfare*

We now quantify the aggregate effects of TPU on entry, US price indices, and additional domestic outcomes. We then compare their magnitude with other pieces of evidence.

Aggregate Price and Welfare.—The overall price index increase from reintroducing TPU in 2005, $\ln P_1 / P_1^D$, is 0.52 log points.[42] In Table 8 we show this is equivalent to a deterministic tariff increase of 13 log points using (17) and the AVE definition in (30). This is roughly one-half of the price index increase predicted by the model if there was no TPU and the United States stopped all imports from China in 2005.

Increasing TPU from an initial equilibrium with a (counterfactual) long-run mean tariff increases the price index by 0.515 log points—almost the same as increasing it at the lower MFN tariffs. This implies the lock-in effect defined in (29) from eliminating TPU on the price index is close to zero because it generates an increase in foreign varieties that is offset by fewer domestic varieties.[43] Thus, the pure risk cost of TPU on the price index is large.

[42] We compute it using the multi-industry version of (24) at fixed tariffs and the decomposition given in (25).

[43] This does not mean that changes in tariffs have little effect on the price index. In fact, the price impact of increasing tariffs to their mean in the absence of uncertainty is 0.43 log points. However, if we lower those tariffs back down under uncertainty the price index will fall by almost as much so the net lock-in effect is close to zero.

These price index effects also apply to the (stationary) effect of TPU on consumer welfare because it is simply $-\mu \ln P_1 / P_1^D$. Namely, the welfare cost of TPU in 2005 is almost one-half that of going to autarky with China. The price index AVE also applies to consumer welfare. Thus, the effect of a TPU increase on the price index and welfare is equivalent to permanently raising the average tariff factor on Chinese goods in 2005 from 4 to 17 log points.

The AVE and autarky comparisons for welfare are relative magnitudes and so independent of the US expenditure share on manufacturing, μ. To provide an absolute effect and place it in context of other large trade shocks, we use the 2005 US expenditure on manufacturing as a share of tradables expenditure and obtain a welfare cost of TPU of 0.45 log points. This is over one-half the cost that Costinot and Rodríguez-Clare (2014) calculate for North America under a worldwide trade war with a uniform tariff of 40 percent. The TPU effect is also substantial when compared to another reference point for the magnitude of gains from trade: Broda and Weinstein (2006) estimate the real income gain from all new imported varieties in the United States between 1990 and 2001 to be 0.8 percent. Neither incorporates the role of uncertainty.[44]

Other Outcomes.—In our setting, the price AVE also applies to various outcomes of incumbent US firms in the differentiated sector, namely their domestic profits, sales, and employment, which are affected by uncertainty and tariffs only indirectly via the price index. The aggregate effects of TPU on domestic firm outcomes also reflect changes in entry decisions. The latter depend directly on uncertainty so their AVE is different from the one for the price index, as shown in Table 8. Reintroducing TPU in 2005 would increase US firm entry by 0.44 log points: equivalent to a 1.8 log point increase in tariffs. The effect on aggregate domestic sales is about 1.3, equivalent to a tariff increase of 5.9. Finally, TPU increases domestic quantities and employment in the differentiated sector by 1.2 log points, equivalent to a 7.3 log point tariff increase on Chinese goods, a sizable permanent tariff change in the context of recent US agreements.

How do these outcomes relate to observed changes in the period 2000–2005? To answer this we identify the differentiated sector with manufacturing, and the numéraire with the remaining tradable sectors (agriculture and mining), as is standard. In this period, we observed a reduction in both gross and net entry of manufacturing establishments. According to the Business Dynamics Statistics Database (US Census) the manufacturing gross entry rate was 7.9 percent and gross exit was 8.7 on average between 2002–2006. We also observed an expansion outside of the manufacturing sector, both in terms of establishments and employment. The sign of these observed changes is predicted by the model after a reduction in TPU.

The quantification can also account for a nontrivial fraction of US manufacturing employment and domestic sales reallocation. Our counterfactuals hold total employment, L, constant and therefore we should interpret the model's prediction

[44] Over 98 percent of Chinese exports to the United States are manufactures. As is standard in most trade models, neither our quantification nor the other ones discussed here take services into account. However, the model and calculations do take into account the large fraction of nontraded goods since many of the differentiated goods are produced by firms that are not productive enough to export. This is reflected in the relatively low values of US imports/consumption captured by the import penetration.

as applying to the manufacturing employment *share* in the tradable sector. Our estimates imply the reduction in TPU in the period 2000–2005 caused this employment share to fall by 1.2 log points (Table 8) and the observed reduction was 3.3 log points. The US sales counterfactual holds total manufacturing expenditure, $E = \mu wL$, constant and implies a 1.3 log point reduction in the US firms' share of manufacturing expenditure; the corresponding observed reduction was 3.3 log points. Thus, the reduction in TPU can account for at least one-third of the reallocation of domestic manufacturing sales and a similar fraction of its employment share in tradables.[45]

Export Entry and Price Index.—We conclude by comparing the quantitative implications for export entry and prices with other information.

The model predicts that at least a fraction $G(c_{sV}^{U})$ of Chinese firms in V export to the United States under state s. The growth in this cutoff is given by (18) and its TPU component is obtained by holding tariffs fixed. Therefore, under a Pareto distribution, the growth in the number of exporters is simply k times that expression. Thus, we can compute the average entry effect of TPU as

$$\mathbb{E}_V \ln n_{1V}/n_{1V}^{D} = k\big(\mathbb{E}_V \ln U_V + \ln P_1/P_1^{D}\big). \tag{31}$$

On average TPU had reduced entry by 54 log points. This is also the change in the number of firms that upgrade since the fraction of exporters that do so is independent of uncertainty in this setting.

The aggregate entry and upgrading effect is 61 log points, which is sizable relative to the growth in the number of Chinese firms exporting to the world over the period 2000–2005 (83 log points, Ma et al. 2014).[46] The AVE for entry is nearly twice as large as for exports (Table 8). Moreover, when we apply the decomposition in (29) to entry we find that most of the TPU effect on entry is attributable to a risk reduction.

The negative effects of TPU on entry and upgrading imply increases in the price index for Chinese varieties. Comparing (15) and (16), the change in the import index for each industry when holding tariffs fixed is $\hat{P}_{1V,x} = \big(\hat{c}_{1V}\big)^{1-\frac{k}{\sigma-1}}$. Thus, the average effect of TPU across industries is

$$\mathbb{E}_V \ln P_{1V,x}/P_{1V,x}^{D} = \left(1 - \frac{k}{\sigma - 1}\right)\big(\mathbb{E}_V \ln U_V + \ln P_1/P_1^{D}\big), \tag{32}$$

which is simply a rescaling of the entry effect in (31). Using the NLLS estimates obtained with export data we compute the terms on the right-hand side and find an average price effect of 15 log points. The aggregate price effect is 17 log points and is obtained by aggregating the computed industry effects using the theoretically consistent weights in (28). These average and aggregate effects are reported in Table 7

[45] A more complete analysis of the effects of TPU on US firm entry and employment requires extending the model to account for features such as the input-output linkages analyzed by Acemoglu et al. (2016).

[46] The aggregate entry effect recomputes the expression in (28) using the entry elasticity for U. The expenditure weights used are the relevant ones to obtain the effect of changes in entry on prices.

and are similar to the estimates in Section IIF when using the empirical counterpart to this price index.

To compare the price effects to a relevant data counterpart, we control for nominal and other shocks common across varieties by focusing on relative prices. The quantification implies a reduction of 17 log points for the price index of Chinese varieties in 2000 to 2005 and a negligible impact for non-Chinese varieties. This is close to the relative ideal price index reduction we measure in that period.[47]

V. Conclusion

We assess the impact of trade policy uncertainty in a tractable general equilibrium framework with heterogeneous firms. Increased TPU reduces investment in export entry and technology upgrading, which in turn reduces trade flows and real income for consumers. We apply the model to China's WTO accession and use it to estimate and quantify the impacts of reducing the TPU faced by Chinese exporters when the United States ended its annual threat to revert to Smoot-Hawley tariffs.

We derive observable, theory-consistent measures of TPU and estimate its effect on trade flows, prices, and welfare. We find a large and robust effect of reducing TPU on China's export growth to the United States. The same measure of TPU does not predict China's exports to other major industrial countries or US import growth from its other nonpreferential trade partners. The reduction in TPU lowered Chinese industry export price indices, as the model predicts. Both the export and price effects of TPU are strongest in industries with high sunk costs of exporting.

Using the estimates of the structural parameters we compute the exact changes in price indices and the effect on entry and sales of domestic and foreign firms. Had the MFN status been revoked, the typical Chinese exporter would have faced an average tariff of 31 percent. The removal of this threat had large effects on Chinese export entry, about 60 log points, and export growth, 32 log points. The quantification indicates the reduction in TPU decreased US manufacturing sales and employment by more than one percent, but also lowered the price index and thus improved consumer welfare by the equivalent of a permanent tariff decrease of 13 percentage points on Chinese goods—a substantial amount of effective protection.

Our findings also point to a broader role of agreements in reducing TPU and generating aggregate welfare gains. For example, if the United States unilaterally threatens to abandon or renegotiate all its trade agreements and raises the tariff threat to a level similar to what China faced, then the US consumer cost would be equivalent to one-third of the cost of trade autarky. Moreover, for a range of applied tariffs an increase in TPU may leave consumers worse off than autarky. Therefore, events such as Brexit and threats to renegotiate agreements can undermine their value even if they lead to no applied policy change.

Future work could explicitly model, quantify, and decompose the relative importance of alternative channels through which TPU may operate (e.g., intermediates and offshoring) as well as its impact relative to that of alternative sources of Chinese

[47] We measure the latter using the industry price index changes in Section IIF and aggregating them for $i =$ China or US nonpreferential trading partners using their respective log change ideal weights, $\Delta \ln P_i \equiv \sum_V w_{V,i} \Delta \ln P_{V,i}$. We obtain $\Delta \ln P_{china} - \Delta \ln P_{non-pref} = -0.6 - 12$.

export changes in own trade policy or the partial dismantling of central planning. It could also be useful to structurally quantify the labor market effects of TPU in the presence of frictions. More generally, our research points to the value of specific data-rich settings to identify the effects of policy uncertainty on economic activity and shows these potentially substantial effects should not be ignored.

Appendix A. Theory Appendix

A. *Entry under Partial Equilibrium*

Proposition 1 derives the equilibrium entry expressions and related results in Section ID. We employ a more general policy transition matrix and show the special case in the text is obtained when $\lambda_{22} = 1$:

$$M = \begin{bmatrix} \lambda_{22} & \lambda_{21} & 0 \\ \lambda_{12} & \lambda_{11} = 1-\gamma & \lambda_{10} \\ 0 & 0 & 1 \end{bmatrix}. \tag{33}$$

PROPOSITION 1 (Policy Uncertainty and Export Entry, Small Exporter): *Under a regime $\Lambda(\tau_m, \gamma)$ with policy uncertainty and where tariff increases are possible, $\tau_2 > \tau_1$ and $u(\gamma) > 0$, the entry cutoff in the intermediate state, c_1^U, is*

(*A*) *unique and $c_1^U = c_1^D U(\omega, \gamma)$, and U is given by (7);*

(*B*) *lower than the deterministic, $c_1^U < c_1^D$, and decreasing in policy uncertainty, $dc_1^U/d\gamma = dU/d\gamma < 0$;*

(*C*) *lower than the cutoff in the low state, $c_1^U < c_0^U = c_0^D$ and $c_1^U/c_0^U = c_1^U/c_0^D = U(\omega, \gamma) \times (\tau_1/\tau_0)^{-\frac{\sigma}{\sigma-1}}$.*

To prove the uniqueness of the industry cutoff in (i), we first establish sufficient conditions for a unique tariff below which each firm enters. We say $\Lambda(\tau_m, \gamma)$ exhibits uncertainty persistence if $\Lambda(\tau_{m+1}, \gamma)$ first order stochastically dominates $\Lambda(\tau_m, \gamma)$ for $m = 0, 1$, which is satisfied by (33).

LEMMA 1 (Entry Threshold): *For any given policy regime $\Lambda(\tau_m, \gamma)$ that exhibits uncertainty persistence, and each firm c from a small exporting country, there is a unique threshold tariff per state, $\tau_s^U(\gamma, c)$, below which a firm enters into exporting.*

PROOF OF LEMMA 1:

Rewriting (2) recursively we have $\Pi_e(a_s, c, \gamma) = \pi(a_s, c) + \beta \mathbb{E}_s \Pi_e(a_s', c, \gamma)$. Substitute in (4) to obtain

$$\Pi(a_s, c, \gamma) - \Pi_e(a_s, c, \gamma) + K = \max\left\{0, \beta\mathbb{E}_s\left[\Pi(a_s', c, \gamma) - \Pi_e(a_s', c, \gamma)\right] - \pi(a_s, c) + K\right\}; \tag{34}$$

$$V_s = \max\left\{0, \beta\mathbb{E}_s V_s' - \pi(a_s, c) + K(1-\beta)\right\}, \tag{35}$$

where the option value of waiting is $V_s \equiv \Pi(a_s, c, \gamma) - \Pi_e(a_s, c, \gamma) + K$ and $\mathbb{E}_s V_s' \equiv \mathbb{E}_s\left[\Pi(a_s', c, \gamma) - \Pi_e(a_s', c, \gamma) + K\right]$.

(i) Entry by firms from small exporting countries have no effect on the importer aggregates. Thus, for given E and P we have $a_s \equiv EP^{\sigma-1}\tau_s{}^{-\sigma}\sigma^{-\sigma}(\sigma-1)^{\sigma-1}$ so $\mathbb{E}_s V_s' = \int V_s\, d\Lambda(\gamma, \tau' | \tau)$.

(ii) Because $-\pi(a_s, c)$ is increasing in τ, it is more attractive to wait at higher tariffs because the second element of (35) and therefore V_s would be higher, all else equal.

(iii) Since Λ exhibits uncertainty persistence we have $\int V_s\, d\Lambda(\gamma, \tau' | \tau + \varepsilon) > \int V_s\, d\Lambda(\gamma, \tau' | \tau)$ if V_s is increasing in τ.

Given (iii), if we start with an increasing V_s the fixed point to this iteration is also increasing in τ. By properties (ii) and (iii), $\beta\mathbb{E}_s V_s' - \pi(a_s, c)$ is increasing in τ, so there is some $\tau_s^U(\gamma, c)$ below which the firm value is higher if exporting and above which the opposite is true. ∎

PROOF OF PROPOSITION 1(A):

Lemma 1 shows that each firm v has a single tariff entry cutoff $\tau_s^U(\gamma, c_v)$. All firms have different cost but face the same τ and γ in the industry so there is a unique entry cutoff for any given τ_m, $c_1^U(\tau_m, \gamma)$, and only those with cost below this enter into exporting.

To show $c_1^U = c_1^D U(\omega, \gamma)$ we first derive $\Pi(a_s, c \leq c_s^U, \gamma)$ if $s = 1$. Starting with (35) and taking the expectation over the possible states we have

$$(36) \quad \mathbb{E}_s V_s' = \lambda_{s,s+1}\left[\beta\mathbb{E}_{s+1} V_s' - \pi(a_{s+1}, c) + K(1-\beta)\right] \quad \text{if } c \leq c_s^U$$

$$= \lambda_{s,s+1}\left[\beta\left(\frac{\lambda_{s+1,s+1}}{1-\beta\lambda_{s+1,s+1}}\left[K(1-\beta) - \pi(a_{s+1}, c)\right]\right) - \pi(a_{s+1}, c) + K(1-\beta)\right]$$

$$= \frac{\lambda_{s,s+1}}{1-\beta\lambda_{s+1,s+1}}\left[K(1-\beta) - \pi(a_{s+1}, c)\right],$$

where the second line uses (35) and takes the conditional expectation starting at $s+1$:

$$(37) \quad \mathbb{E}_{s+1} V_s' = \lambda_{s+1,s+1}\left[\beta\mathbb{E}_{s+1} V_s' - \pi(a_{s+1}, c) + K(1-\beta)\right] \quad \text{if } c \leq c_s^U$$

$$= \frac{\lambda_{s+1,s+1}}{1-\beta\lambda_{s+1,s+1}}\left[K(1-\beta) - \pi(a_{s+1}, c)\right].$$

We can then show by contradiction that $c_s^U < c_s^D$. Suppose instead that $c_s^U \geq c_s^D$ so the marginal deterministic firm has nonpositive option value of waiting at s

under uncertainty, i.e., $V_s(c_s^D) \leq 0$. By definition $\pi(a_s, c_s^D) = K(1-\beta)$ and so $V_s(c_s^D) = \max\{0, \beta \mathbb{E}_s V_s'(c_s^D)\}$. Moreover, $\pi(a_{s+1}, c_s^D) < K(1-\beta)$ when $\tau_s < \tau_{s+1}$, which implies that $\mathbb{E}_s V_s' > 0$ and therefore $V_s(c_s^D) > 0$. This contradiction implies that $c_s^U < c_s^D$.

The marginal firm at s under uncertainty has

$$V_s(c_s^U) = 0 = \max\left\{0, \beta \mathbb{E}_s\left[V_s'(c_s^U)\right] - \pi(a_s, c_s^U) + K(1-\beta)\right\} \tag{38}$$

and we can solve for c_s^U by equating the second term in curly brackets to zero and simplifying to obtain

$$\pi(a_s, c_s^U) + \beta \lambda_{s,s+1} \frac{\pi(a_{s+1}, c_s^U)}{1 - \beta \lambda_{s+1,s+1}} = K(1-\beta)\left(1 + \frac{\beta \lambda_{s,s+1}}{1 - \beta \lambda_{s+1,s+1}}\right). \tag{39}$$

Starting at $s = 1$, replacing π using (1) and simplifying we obtain the cutoff expression (6) in the text

$$a_1 \left(c_1^U\right)^{1-\sigma}\left[1 + \frac{\beta \lambda_{12}}{1 - \beta \lambda_{22}} \frac{a_2}{a_1}\right] = K(1-\beta)\left(1 + \frac{\beta \lambda_{12}}{1 - \beta \lambda_{22}}\right)$$

$$a_1 \left(c_1^U\right)^{1-\sigma}\left[1 + u(\gamma) \frac{a_2}{a_1}\right] = K(1-\beta)\left(1 + u(\gamma)\right)$$

$$c_1^U = \left(\frac{a_1}{K(1-\beta)}\right)^{\frac{1}{\sigma-1}} \times \left(\frac{1 + u(\gamma)\omega}{1 + u(\gamma)}\right)^{\frac{1}{\sigma-1}}. \tag{40}$$

The last line uses the expressions given in the main text: $\omega \equiv a_2/a_1 = (\tau_2/\tau_1)^{-\sigma}$, $\gamma \equiv 1 - \lambda_{11}$, $\gamma \lambda_2 = \lambda_{12}$, and $u(\gamma) \equiv \frac{\beta \gamma \lambda_2}{1 - \beta \lambda_{22}}$ where in the text we assumed $\lambda_{22} = 1$.∎

PROOF OF PROPOSITION 1(B):

Since $c_1^U / c_1^D = U$ we must show $U < 1$ if and only if tariff increases are possible. From the definition in (7) we obtain $U < 1$ if and only if $u(\gamma)\omega < u(\gamma)$, which is true if and only if $\tau_2 > \tau_1$ and $\gamma \lambda_2 > 0$ so that $u(\gamma) > 0$. Since $c_1^U = c_1^D U(\omega, \gamma)$ (part A) we can use (7) to obtain

$$\gamma \frac{d \ln c_1^U}{d\gamma} = \gamma \frac{d \ln U_1(\omega, \gamma)}{d\gamma} = \frac{1}{\sigma - 1} \frac{u}{1+u} \frac{\omega - 1}{1 + u\omega} < 0, \tag{41}$$

where the inequality holds only if $\omega < 1 \Leftrightarrow \tau_2 > \tau_1$ and $u(\gamma) > 0$. ∎

PROOF OF PROPOSITION 1(C):

If $\tau_2 > \tau_1$ *and* $u > 0$ then $c_1^U < c_1^D$, (part B). Since $\lambda_{00} = 1$ we have $c_0^D = c_0^U$. If $\tau_0 \leq \tau_1$ then $c_1^D \leq c_0^D$ (from (3)) and therefore $c_1^U < c_1^D \leq c_0^D = c_0^U$. Using c_1^U from part (A) $c_1^U / c_0^D = U(\omega, \gamma) \times (c_1^D / c_0^D) = U(\omega, \gamma) \times (\tau_1/\tau_0)^{-\frac{\sigma}{\sigma-1}}$, where the last equality uses (3), and the definition of a_s for fixed E and P. ∎

B. *Upgrading Cutoffs*

After paying the initial export entry cost, K, the firm can incur an additional K_z to lower its marginal export cost by a fraction $z < 1$ of the industry's baseline variable export cost d. Its operating export profits become $\pi_v = a_s(zc_v)^{1-\sigma}$, so they grow by a factor $z^{1-\sigma} - 1$. If policy is deterministic, a firm will be indifferent between upgrading or not if its marginal cost of production is c_{sz}^D, which is defined by $\pi(a_s, zc_{sz}^D) - \pi(a_s, c_{sz}^D) = K_z(1-\beta)$:

$$(42) \qquad c_{sz}^D = \left[\frac{a_s(z^{1-\sigma}-1)}{K_z(1-\beta)}\right]^{\frac{1}{\sigma-1}}.$$

We consider a sufficiently high fixed cost of upgrading such that only the most productive and thus only a fraction of exporters upgrade. This implies that the marginal entrant into exporting will not upgrade and therefore the entry cutoff, c_s^D, is still given by (3). In this case the upgrade cutoff is proportional to the entry cutoff by an upgrading parameter, ϕ, which is independent of the policy. Thus, we have

$$(43) \qquad \frac{c_{sz}^D}{c_s^D} = \phi \equiv \left[(z^{1-\sigma}-1)\frac{K}{K_z}\right]^{\frac{1}{\sigma-1}} < 1.$$

Below we show that if only a fraction of exporters upgrade then under uncertainty we also obtain an upgrade to entry cutoff ratio equal to ϕ. This is a result we use in the aggregation and estimation. Given the similarities with the entry decision, here we just outline the main steps and modifications to incorporate upgrading.

In order to use the entry cutoffs derived in the text we must ensure that ϕ is sufficiently low to ensure that even the most productive marginal entrant would never upgrade, i.e., even a firm that is indifferent about entering under the worst policy state would never upgrade when conditions improved. Formally, the condition for the upgrading parameter to be sufficiently low if $\phi < \overline{\phi}$ and $\overline{\phi}$ is defined by $c_{0z}^U(\overline{\phi}) = c_2^U$, where c_2^U is the entry cutoff under column 2 tariffs previously derived and $c_{0z}^U(\phi)$ is the upgrade cutoff under the agreement state.

At a given state s a firm will be just indifferent between upgrading if it has cost c_{sz}^U, which is implicitly defined by the equality of the expected value of exporting using the upgraded technology net of the sunk cost and the expected value of waiting while using the old technology:

$$(44) \qquad \Pi_e(a_s, c) = \max\{\Pi_{ez}(a_s, zc) - K_z, \beta\mathbb{E}_s\Pi_e(a_s', c)\}.$$

The upgrade factor z multiplies the cost in the expression of operating profits for each period after upgrading. The key differences relative to the entry decision are that a firm that has not upgraded makes positive export profit today. Moreover, in the following period the firm either transitions to the same state or to column 2 tariffs, in which case it continues to use the initial technology, or transitions to the agreement state, where it will upgrade. Since z is state independent it is straightforward to show that the expected value of exporting under the new technology is

$$\Pi_{ez}(a_s, z c_{sz}) = z^{1-\sigma} \Pi_e(a_s, c_{sz}) \quad \text{for each } s. \tag{45}$$

When a is decreasing in tariffs (τ) the solution is to enter when current tariffs are below a firm-specific threshold tariff. The cutoff at any particular a must satisfy the following upgrade indifference condition:

$$\Pi_{ez}(a_s, z c_{sz}^U) - K_z = \Pi_e(a_s, c_{sz}^U) \quad \text{for each } s. \tag{46}$$

Solving this yields $c_{1z}^U = U(\omega, \gamma)\, c_{1z}^D$ and thus the elasticity with regard to the uncertainty factor is the same as the entry cutoff's. Moreover, the relationship between the cutoffs is $\frac{c_{1z}^U}{c_1^U} = \frac{c_{1z}^D U(\omega,\gamma)}{c_1^D U(\omega,\gamma)} = \phi$. Since the upgrade cutoff is proportional to the entry one by a fixed factor that is independent of policy, we can replace it to derive the structural industry gravity equation that aggregates without requiring knowledge of which firms actually upgrade in the industry.

Appendix B. Data Appendix

- *Change in Ad Valorem Tariffs* $\Delta \ln \tau_V$: Log change in 1 plus the statutory ad valorem MFN tariff rate aggregated to the HS-6 level between 2005 and 2000. Source: TRAINS via WITS
- *Change in AVE Tariffs* $\Delta \ln \tau_V$: Log change in 1 plus the ad valorem equivalent (AVE) of the MFN tariff rate at the HS-6 level between 2005 and 2000. For specific tariffs, the AVE is given by the ratio of unit duty to the average 1996 import unit value. Source: TRAINS for tariff rates and COMTRADE for unit values via WITS
- *Column* 2 *Tariff* τ_{2V}: Log of 1 plus the column 2 tariff rate at the HS-6 level. For specific tariffs at the HS-8, base year unit values from 1996 used for all years to compute the AVE tariff and then average at the HS-6 level. Source: TRAINS for tariff rates and COMTRADE for unit values via WITS
- *Uncertainty Pre-WTO:* Measure of uncertainty from the model $1 - (\tau_{2V}/\tau_{1V})^{-\sigma}$ computed using year 2000 column 2 and MFN tariff rates.
- *Change in NTBs:* Indicators for temporary trade barriers in-force including anti-dumping duties, countervailing duties, special safeguards, and China-specific special safeguards. Data are aggregated up to HS-6 level. Source: Bown (2015)
- *Change in MFA:* Indicators for in-force Multi-Fiber Agreement on Textiles and Clothing (MFA/ATC) quotas aggregated to the HS-6 level and concorded through time. Source: Brambilla, Khandelwal, and Schott (2010)
- *Change in Transport Costs* $\Delta \ln D_V$: Log change in the ratio of trade values inclusive of costs, insurance, and freight (CIF) to free on board value (FOB). Source: CIF/FOB ratios constructed at HS-6 level using disaggregated data from NBER

- *US Import Growth:* Change in log US imports by HS-6 industry between 2000 and 2005. Source: NBER
- *Chinese Export Growth* (*Non-US Destinations*)*:* Change in log Chinese exports by HS-6 industry between 2000 and 2005 to Japan or EU-15 (members of EU by 1995). Source: COMTRADE
- *Chinese Variety Growth:* Change in log count of HS-10 products exported to United States within each HS-6 industry from 2000 to 2005. Source: NBER
- *Chinese Price Index Growth:* Change in log ideal price index of exports to the United States by HS-6 industry from 2000 to 2005. Source: Authors calculations described in online Appendix C.5
- *Sunk Cost Classification:* Indicator for top two terciles of industries according to their export sunk cost estimate. Source: Authors calculations described in online Appendix C.4
- *Import Penetration in Manufacturing:* US manufacturing imports over US expenditure on manufacturing, $R_{Ch,t} / E_t$, where E_t is total manufacturing shipments (US Census Bureau) less net manufacturing exports (USITC).

We use the published UN Statistics Division concordances to map the HS 2002 codes into the HS 1996 to match the policy data with the trade data over time. To compute price indices we also match the ten-digit level import flows over time, for which we use the method in Pierce and Schott (2012). We then aggregate up to the six-digit level of HS 1996 when constructing price indices or product variety counts as needed and described in online Appendix C.5. A small fraction of HS-10 codes are reassigned across multiple HS-6 and can't be tracked longitudinally without arbitrary aggregation in which case we drop them for all years.

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