Trade policy uncertainty and innovation: Evidence from China

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Abstract

This paper investigates the effect of trade policy uncertainty (TPU) on innovation using patent data. Access to large markets is an important driver of innovation, but uncertainty generates an option value of waiting which reduces investment, and may attenuate an important source of dynamic gains from trade. This paper exploits China's accession to the WTO, and the resulting conferral of permanent MFN status by the US, to estimate the causal effect of TPU on innovation in Chinese industries. Using a triple difference in differences, I find higher patenting growth in industries *ex-ante* exposed to larger potential profit losses than in industries exposed to lower potential profit losses, after the source of uncertainty is eliminated.

1 Introduction

This paper investigates the effect of trade policy uncertainty on innovation using patent data.

Market size is an important driver of innovation. Recent empirical literature[1] has quantified the effect of improved access to foreign markets after trade liberalization as large, and shed light on an important source of dynamic gains from trade. However, most of the literature so far has considered a deterministic framework in which, after tariffs are reduced, they remain at low levels, with no or small possibility to be risen in the future. Nevertheless, unilateral initiatives of trade liberalization, or some trade

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[1] See for example Lileeva and Trefler (2010), Bustos (2011) and Coelli et al. (2018).

agreement may not be credible, and therefore there may remain a positive probability of sudden tariff increases or trade wars, even if effective tariffs are low. Uncertainty with respect to future foreign market access may reduce or delay investment in technological innovation and productivity. As a result, in the presence of uncertainty, some of the dynamic gains from trade documented in the literature may not materialize, or may be attenuated.

The theoretical mechanism of investment under uncertainty goes back to Bernanke (1983), and is well understood in the literature. In the presence of an irreversible investment choice under uncertainty, an optimizing investor must take the timing of her decision into account. Uncertainty about future conditions generates an option value of waiting, which may lead to delay investment. However, uncertainty is difficult to measure empirically, and it proves to be difficult to identify a plausibly exogenous source of variation which allows to estimate the causal effect of uncertainty on innovation.

This paper looks at the trade relation between the US and China, which offers a plausibly exogenous source of variation to identify the effect of trade policy uncertainty (TPU) on innovation. More precisely, the paper exploits China's accession to the WTO, and the resulting conferral of Permanent Normal Trade Relation[2] (MFN status) by the US, which eliminates the annual US threat of imposing high tariffs on Chinese imports.

China obtained MFN status from the US in 1980, but this was subject to annual renewal. While nearly automatic in the beginning, the renewal process became subject of contentious debate after the Tienanmen Square incident in 1989. All industries faced the same probability of switching back to high column 2 tariffs applied by the US to non-market economies, but the potential losses implied by this worst case scenario varied across industries, as they depended on the difference between MFN tariffs and the much higher column 2 tariffs, which are industry specific. I follow Pierce and Schott (2016), Handley and Limão (2017), and Pierce and Schott (2017) and use this source of variation to identify the effect of TPU reduction on innovation. I use the (log) difference between column 2 and MFN tariff, as a proxy for potential profit losses had the US reverted to column 2 tariffs. 80% of the variation in this measure is explained by variation in the columnn 2 tariffs, which were set in 1930, and thus makes this measure plausibly exogenous.

Empirically, I measure innovation using patent data. I use the comprehen-

[2]Normal Trade Relations (NTR) is the US term for MFN. I will use the two terms interchangeably. MFN or NTR tariffs indicate the same tariffs, and column 2 or non-NTR tariffs are also used as synonyms.

sive dataset Patstat, which allows me to observe nearly every firm worldwide that files a patent, when the patent was filed, the technical class of the patent, which I match to industries and product classes, and in which country the firm is located at the time of application. Using this rich set of information, I construct the change in the log stock of patents for all industries and countries that patent worldwide. Then, I use a generalized difference-in-difference-in-difference and compare growth in patenting in industries initially exposed to high *vs* low potential profit losses (1^{st} difference), before and after PNTR conferral (2^{nd} difference), across countries (3^{rd} difference).

The main advantage of this approach is that I can difference out industry trends in patenting that could bias the estimated coefficient in a simple difference in differences. This is important because after WTO accession China implemented several reforms to liberalize its economy, and it is possible that industries with high and low potential losses have different trends in patenting after 2001 due to these reforms.

Industries exposed to larger differences between column 2 and MFN tariffs before 2001 are expected to innovate relatively faster than industries exposed to lower differences when uncertainty is reduced. Consistently with theory, I find that patents growth in industries *ex-ante* exposed to higher potential profit losses is higher than in industries exposed to lower potential profit losses, after the source of uncertainty is eliminated, and the difference is statistically significant. To asses the validity of the analysis, I conduct two robustness tests that exploit similarities and differences in the trade policy regime change. First, I look at Vietnam, which obtains permanent MFN status in 2007 after joining the WTO. The case of Vietnam is similar to one of China in the annual renewal of temporary MFN status, but it differs in that it is characterized by no uncertainty related to the renewal process. Second, I look at the case of Taiwan. Like China, Taiwan joins the WTO in 2002, but unlike China, it has never faced an annual renewal of its MFN status. In both cases there should be no or little effect of trade policy uncertainty on innovation. Consistently with theoretical predictions, the I find no significant effect of TPU on patent growth in Vietnam and in Taiwan.

The paper is related to different strands of literature. It speaks to the empirical literature on economic uncertainty and investment as in Bloom et al. (2007) and Baker et al. (2016). It also relates to the literature looking more specifically at TPU as Pierce and Schott (2016), Handley and Limão (2017), Feng et al. (2017), Handley and Limão (2015), Pierce and Schott (2017), and Amiti et al. (2017). Differently from these papers, that focus primarily on firm dynamic export decisions, I look at a different outcome, namely investment in R&D as measured by patent data.[3] Finally, the paper relates to the literature analyzing the complementarities between trade liberalization, innovation and technological upgrading as in Bustos (2011), Lileeva and Trefler (2010), and Coelli et al. (2018). The difference between these papers and this analysis is that I focus on an R&D investment decision when foreign market access is uncertain.

The paper contributes to the literature by providing evidence on the link between trade policy uncertainty and investment in technological innovation. It shows that ensuring secure access to foreign markets is important for the dynamic gains from trade arising from R&D investment to fully materialize, even when effective tariffs are already low. It also contributes to the debate on the value of credible trade agreement.

The rest of the paper is organized as follows. Section 2 presents the theoretical framework. Section 3 discusses the identification strategy and discusses the empirical model. Section 4 describes the data. Section 5 presents the empirical results. Section 6 concludes.

2 Economic framework

To analyze the effect of trade policy uncertainty on innovation, I start by presenting a basic economic framework to describe the main mechanisms, and provide the intuition for the empirical strategy.

To do so, I consider a variation of Handley and Limão (2017), and focus on the firm's decision to invest in R&D. The technology choice is binary as in Bustos (2011).

2.1 Theoretical mechanism

2.1.1 Set up

Consider a model with two countries, home (China) and foreign (US). Let n denote the country, with $n = d$ for home and $n = x$ for foreign country respectively. Consider for simplicity a single differentiated sector j,[4] characterized by monopolistic competition, and in which each firm produces a variety i using only labor. Firms are heterogeneous in productivity, indexed

[3] Pierce and Schott (2017) look at the manufacturing investment and capital stock in the US, and find that rising import competition from China resulting from reduced TPU decreases investment on average.

[4] Since there is only one differentiated sector, I will omit the sector subscript.

by φ_i.
Initial productivity is exogenously given, but firms can increase their productivity by investing in new technology. There is a sunk cost I associated with R&D investment. This sunk investment cost captures start-up costs like purchasing specific assets, hiring or training specialized workers, acquiring information on new technologies, etc. that cannot be recovered.[5] The innovation choice is binary as in Bustos (2011): investment in R&D produces a high type technology,[6] which reduces the marginal cost of production from $\frac{1}{\varphi_{i0}}$ to $\frac{1}{\varphi_{i1}}$; if a firm does not invest, it keeps producing with a low type technology and initial productivity φ_{i0}.
A firm producing variety i faces an *ad valorem* tariff $T_x = \tau_x - 1$ to serve the foreign market. All firms in the differentiated industry face the same tariff. There is no sunk foreign market entry cost,[7] or per-period fixed cost, which implies that all firms active in the domestic market also export to the foreign market.[8] Finally, in each period there is an exogenous probability of exit $1 - \beta$, with $\beta \in (0, 1)$, independent of firm's productivity.
Consumers have CES preferences across varieties, with constant elasticity of substitution $\sigma > 1$. This generates a home demand $q_{id} = A_d p_{id}^{-\sigma}$, and a foreign demand $q_{ix} = A_x p_{ix}^{-\sigma}$, where A_d is a measure of domestic market size, and A_x is a measure of foreign market size.[9] p_{ix} is consumer price, inclusive of tariff;[10] hence, exporters receive p_{ix}/τ per unit sold abroad. Under monopolistic competition and CES preferences, the profit maximizing price is a constant markup over marginal cost, so a firm will charge: $p_{in} = \frac{\sigma}{\sigma-1}\frac{\tau_n}{\varphi_i}$, where n denotes the destination country and can be either domestic (d) or foreign (x), the wage is normalized to one for simplicity, $\varphi_i = \varphi_{i1}$ if the firm innovates, and $\varphi_i = \varphi_{i0}$ if the firm does not innovate.
Equilibrium per-period operating profits as a function of firm's technology investment choice are given by the sum of domestic and export profits. For

[5] "Most expenditures on R&D are, by their very nature, sunk costs. The resources spent on a scientist to do research cannot be recovered. Once his time is spent, it is spent"(Stiglitz et al., 1987, p. 928).

[6] For simplicity, I ignore the fact that the outcome of the innovation process is uncertain.

[7] Including a sunk cost to enter the foreign market would generate an option value associated with entry. Although empirical evidence suggests that this sunk cost is relevant, I abstract from this to focus on the R&D investment decision. Handley and Limão (2017) analyze the effect of a sunk cost of exporting on firm's foreign market entry decision, and find that policy uncertainty substantially reduces firms' entry.

[8] There is also no endogenous exit

[9] $A_n = E_n P_n^{\sigma-1}$, where E is the demand shifter, and $P_n^{\sigma-1}$ is the CES price index for the differentiated sector.

[10] $\tau_d = 1$ in the domestic market, and $\tau_x \geq 1$ abroad

a firm producing with the low type technology, profits are:

$$\pi(\varphi_{i0}) = \pi_d(\varphi_{i0}) + \pi_x(\varphi_{i0}) = B_d\varphi_{i0}^{\sigma-1} + B_x\tau_x^{-\sigma}\varphi_{i0}^{\sigma-1} \tag{1}$$

If a firm invests in R&D, profits are:

$$\pi(\varphi_{i1}) = \pi_d(\varphi_{i1}) + \pi_x(\varphi_{i1}) = B_d\varphi_{i1}^{\sigma-1} + B_x\tau_x^{-\sigma}\varphi_{i1}^{\sigma-1}, \tag{2}$$

where $B_n = (\sigma-1)^{\sigma-1}\sigma^{-\sigma}A_n$

2.1.2 Uncertainty and innovation decision

Consider the problem of a firm, located in the home country, that has the option to invest in an R&D project to increase its productivity, but faces uncertainty with respect to future foreign market conditions. A larger market makes it more profitable for the firm to invest in R&D. However, foreign market access is uncertain, as it depends on the state of trade policy in future periods. Specifically, there is uncertainty with respect to foreign applied tariffs, $T = \tau - 1$.[11] At any period t, the current value of τ_t is known, but future values τ_{t+1} are random variables. At each period t, the firm faces a binary choice: pay a sunk cost I to invest in R&D, or wait until next period, when the same choice will be available again. The only source of uncertainty is τ and the exogenous probability of survival β.
To understand the role of uncertainty, it is useful to consider the firm's dynamic problem without uncertainty first.
The expected value from investing in R&D is given by the stream of domestic and export profits obtained using the productivity enhancing technology:

$$\Pi^I(\tau_s, \varphi_1) = \Pi_d^I(\varphi_1) + \Pi_x^I(\tau_s, \varphi_1), \tag{3}$$

where expected domestic profits, $\Pi_d^I(\varphi_1)$, without time discounting, are given by

$$\Pi_d^I(\varphi_1) = \pi_d(\varphi_1) + \sum_{t=1}^{\infty}\beta^t\pi_d(\varphi_1) = \frac{\pi_d(\varphi_1)}{1-\beta}, \tag{4}$$

and expected export profits, $\Pi_x^I(\tau_s, \varphi_1)$, are given by

$$\Pi_x^I(\tau_s, \varphi_1) = \pi_x(\tau_s, \varphi_1) + \mathbb{E}_s\sum_{t=1}^{\infty}\beta^t\pi_x(\tau_s', \varphi_1). \tag{5}$$

[11] Since $\tau_d = 1$ in the domestic market, and $\tau_x \geq 1$ abroad, I omit the x subscript, and use τ to denote τ_x to avoid redundant notation.

$\mathbb{E}_s$ denotes the expectation over future values of τ conditional on the information available in the current state of trade policy, s, and φ_1 is firm's productivity when using the high type technology. The variety subscript i is omitted.

The expected value of the firm without upgrading is given by the stream of domestic and export profits obtained by using the low type technology:

$$\Pi(\tau_s, \varphi_0) = \Pi_d(\varphi_0) + \Pi_x(\tau_s, \varphi_0), \tag{6}$$

where expected domestic profits, $\Pi_d(\varphi_0)$, are given by

$$\Pi_d(\varphi_0) = \pi_d(\varphi_0) + \sum_{t=1}^{\infty} \beta^t \pi_d(\varphi_0) = \frac{\pi_d(\varphi_0)}{1-\beta}, \tag{7}$$

and expected export profits, $\Pi_x(\tau_s, \varphi_0)$, are given by

$$\Pi_x(\tau_s, \varphi_0) = \pi_x(\tau_s, \varphi_0) + \mathbb{E}_s \sum_{t=1}^{\infty} \beta^t \pi_x(\tau_s', \varphi_0). \tag{8}$$

where φ_0 is firm's productivity when using the low type technology.

If there is no uncertainty over future market access conditions, summarized by τ_s, the optimal investment decision is to invest whenever the expected value from investing net of the sunk investment cost is higher than the expected value of producing with the low type technology; and there is no option value of waiting. The investment indifference condition is:

$$[\pi_d(\varphi_1) - \pi_d(\varphi_0)] + \left[\pi_x(\tau_s^D, \varphi_1) - \pi_x(\tau_s^D, \varphi_0)\right] = I(1-\beta), \tag{9}$$

where τ_s^D denotes the value of τ_s that satisfies this condition in the deterministic case.

If future foreign market access is uncertain, instead, the firm must decide whether to invest today, or to keep producing with the low type technology and wait until conditions improve. In the next period, the same choice will be available again. This dynamic investment decision takes the form of an optimal stopping problem, where stopping corresponds to investing, and continuation corresponds to waiting. The Bellman equation for the firm's decision problem is given by

$$F(\tau_s, \varphi) = \max\left\{\Pi_d^I(\varphi_1) - \Pi_d(\varphi_0) + \Pi_x^I(\tau_s, \varphi_1) - \Pi_x(\tau_s, \varphi_0) - I, \beta \mathbb{E}_s F(\tau_s', \varphi)\right\}. \tag{10}$$

Investment is optimal whenever

$$\Pi_d^I(\varphi_1) - \Pi_d(\varphi_0) + \Pi_x^I(\tau_s, \varphi_1) - \Pi_x(\tau_s, \varphi_0) - I > \beta \mathbb{E}_s F(\tau_s', \varphi), \tag{11}$$

and waiting is optimal when the opposite is true.
The solution to this optimal stopping problem takes the form of a threshold value of τ_s, which divides the range of τ_s into a 'continuation region' and a 'stopping region': if $\tau_s > \bar{\tau}_s$ it is optimal to wait; if $\tau_s < \bar{\tau}_s$ if is optimal to invest.[12] The cutoff $\bar{\tau}_s$ must satisfy

$$\Pi_d^I(\varphi_1) - \Pi_d(\varphi_0) + \Pi_x^I(\bar{\tau}_s, \varphi_1) - \Pi_x(\bar{\tau}_s, \varphi_0) - I = \beta \mathbb{E}_s F(\bar{\tau}_s', \varphi). \tag{12}$$

Thus, under uncertainty, the investment indifferent condition becomes:

$$F(\bar{\tau}_s, \varphi) = \Pi_d^I(\varphi_1) - \Pi_d(\varphi_0) + \Pi_x^I(\bar{\tau}_s, \varphi_1) - \Pi_x(\bar{\tau}_s, \varphi_0) - I. \tag{13}$$

To understand the role of uncertainty, it is useful to rearrange (10) by subtracting $\Pi_d^I(\varphi_1) - \Pi_d(\varphi_0) + \Pi_x^I(\tau_s, \varphi_1) - \Pi_x(\tau_s, \varphi_0) - I$ from both sides of the equal sign to obtain[13]

$$\begin{aligned}
F(\tau_s,&\varphi) - \Pi_d^I(\varphi_1) + \Pi_d(\varphi_0) - \Pi_x^I(\tau_s, \varphi_1) + \Pi_x(\tau_s, \varphi_0) + I \\
&= \max\{0, \beta \mathbb{E}_s \Big[F(\tau_s', \varphi) - \Pi_d'^I(\varphi_1) + \Pi_d'(\varphi_0) - \Pi_x^I(\tau_s', \varphi_1) + \Pi_x(\tau_s', \varphi_0)\Big] \\
&\qquad - [\pi_d(\varphi_1) - \pi_d(\varphi_0)] - [\pi_x(\tau_s, \varphi_1) - \pi_x(\tau_s, \varphi_0)] + I\} \qquad (14) \\
V_s \quad &= \max\{0, \beta \mathbb{E}_s V_s' - [\pi_d(\varphi_1) - \pi_d(\varphi_0)] - [\pi_x(\tau_s, \varphi_1) - \pi_x(\tau_s, \varphi_0)] \\
&\qquad + (1-\beta) I\} \qquad (15)
\end{aligned}$$

where $V_s \equiv F(\tau_s, \varphi) - \Pi_d^I(\varphi_1) + \Pi_d(\varphi_0) - \Pi_x^I(\tau_s, \varphi_1) + \Pi_x(\tau_s, \varphi_0) + I$ is the option value of waiting. $\pi_d(\varphi_1) - \pi_d(\varphi_0)$ and $\pi_x(\tau_s, \varphi_1) - \pi_x(\tau_s, \varphi_0)$ are the one-period difference in domestic and export profits by using the high *versus* low type technology, which are given up by waiting, and I is the saved sunk investment cost from postponing the decision to invest in R&D. When $\tau_s = \bar{\tau}_s$ the option value of waiting is zero, and postponing is worthless. Compared to a situation without uncertainty, the existence of an option value of waiting requires the expected return of investing in R&D to be

[12] Under reasonable assumption the cutoff value of $\bar{\tau}_s$ is unique. First, it is required to assume positive persistence in uncertainty. Second, the flow payoff from continuation, zero in this case, relative to the termination payoff, must be a monotonic function; when this function is increasing in τ_s, then investment is optimal when $\tau_s < \bar{\tau}_s$.

[13] I use the fact the (5) can be rewritten recursively as $\Pi_x^I(\tau_s, \varphi_1) = \pi_x(\tau_s, \varphi_1) + \beta \mathbb{E}_s \Pi_x^I(\tau_s', \varphi_1)$. (4), (7), and (8) can be rearranged in the same way.

higher, and thus investment in R&D is lower.
This simple economic framework is helpful to understand how incentives to conduct R&D activities for Chinese firms change after 2001. When China enters the WTO, the possibility of sudden increases in applied tariffs by the US disappears: an important source of foreign market access uncertainty is resolved and thus the option value of waiting becomes zero. The firm decision problem becomes a static one, and the firm invests whenever the expected value of export and domestic profits using the high technology, net of the sunk investment cost, exceeds the expected value of export and domestic profits with the low technology, as described in (9).

2.2 Trade policy regime

To understand the effect of TPU on innovation, it is useful to think about China's MFN temporary status in the 90's as an intermediate policy state. Each year, there is a probability $1-\gamma$ that the US renews this status. With probability γ the US revokes China's MFN status, in which case China goes back to a high protection state in which column 2 tariffs apply with probability λ, or enters a (credible) trade agreement in which MFN tariffs apply with probability $1-\lambda$.[14]
There is only trade policy uncertainty in the intermediate state ($\gamma > 0$), whereas γ=0 after the US reverts to column 2 tariffs or after a credible trade agreement between the US and China is signed.
All firms have the same believes about γ and λ, and are exposed to the same possibility of a trade policy shock.
Formally, the trade policy regime is characterized by a Markov process with three possible policy states as in Handley and Limão (2017). The policy states are: column 2 tariffs (s=2), temporary MFN tariffs (s=1), and a credible trade agreement (s=0), with the associated tariff values $\tau_2 \geq \tau_1 \geq \tau_0$. Let $\lambda_{ss'}$ denote the transition probability from state s to s'. The policy transition matrix S summarizes the transition probabilities for all possible states:

$$S = \begin{bmatrix} \lambda_{00} & 0 & 0 \\ \lambda_{10} & \lambda_{11} & \lambda_{12} \\ 0 & 0 & \lambda_{22} \end{bmatrix} \tag{16}$$

In this specific context, $\gamma \in (0,1)$ in the 90s, while it becomes zero after China joins the WTO in 2001, and thus uncertainty with respect to US

[14]The same qualitative predictions can be obtained if the probability of a trade agreement were ignored. In the presence of uncertainty, only the possibility of a worst case scenario matters, while the possibility of good news doesn't affect the investment decision.

trade policy is resolved. I will use this change in γ after 2001 as a policy shock to identify the effect of uncertainty on innovation. This shock is common across industries, but the relative difference in profits under temporary MFN and column 2 tariffs status varies across industries, and provides the source of variation for the empirical analysis.

2.3 Partial equilibrium

To understand the effect of TPU on firms' R&D investment, it useful compare the productivity threshold level that induce firms to innovate under a deterministic scenario and under uncertainty. Consider a partial equilibrium in which applied tariffs τ_s are the only source of uncertainty, and changes in trade policy state leave the aggregate variables E_n and P_n unchanged.

Consider the deterministic case first, where trade policy is in one of the three possible states $s = \{0, 1, 2\}$ and is not expected to change. For each firm i in the differentiated sector, there is one value of τ_s^D that satisfies the innovation indifference condition (9). If τ_s is below the firm's specific threshold, then the firm finds it optimal to invest in R&D. Since all firms in the differentiated sector only differ according to their productivity, it is possible to find is a threshold productivity level for the industry, φ_s, such that all firms with productivity at or above this threshold will invest in R&D.

To find the productivity cutoff φ_s, define as in Bustos (2011) $\varphi_0 \equiv \varphi$ and $\varphi_1 = \eta\varphi_0 \equiv \eta\varphi$, with $\eta > 1$. Using the expressions for domestic and export profits, the innovation indifference condition (9) gives the productivity cutoff in the benchmark deterministic case:

$$\varphi_s^D = \left(\frac{I(1-\beta)}{(\eta^{\sigma-1} - 1)(B_d + B_x \tau_s^{-\sigma})} \right)^{\frac{1}{\sigma-1}} \tag{17}$$

Consider now a firm in the intermediate state, $s = 1$, with MFN tariffs subject to annual renewal. The productivity threshold with uncertainty is given by the solution to the Bellman equation in (10). By rewriting the Bellman as in (14), the marginal firm has

$$V_s\left(\varphi_s^U\right) = 0 \tag{18}$$

$$= \max\{0, \beta \mathbb{E}_s V_s'\left(\varphi_s^U\right) - \left[\pi_d(\eta\varphi_s^U) - \pi_d(\varphi_s^U)\right] - \left[\pi_x(\tau_s, \eta\varphi_s^U) - \pi_x(\tau_s, \varphi_s^U)\right] + (1-\beta)I\}, \tag{19}$$

and the cutoff productivity level φ_s^U is found by equating the second element in the curly bracket to zero. Starting at the intermediate policy state,

$s = 1$, and replacing π_x and π_d with the equations (1) and (2), the productivity cutoff in the intermediate state is given by

$$\varphi_1^U = \left(\frac{I(1-\beta)}{(\eta^{\sigma-1}-1)\left(B_d + B_x \tau_1^{-\sigma} U(\gamma,\omega)\right)} \right)^{\frac{1}{\sigma-1}} \tag{20}$$

$$U(\gamma,\omega) \equiv \frac{1+u(\gamma)\omega}{1+u(\gamma)} \tag{21}$$

$U(\gamma,\omega)$ is an uncertainty factor, and if $U(\gamma,\omega) < 1$, then $\varphi_1^U > \varphi_1^D$, and investment in R&D is reduced under uncertainty. $\omega \equiv \left(\frac{\tau_2}{\tau_1}\right)^{-\sigma} < 1$ is the ratio of export profits under column 2 tariffs, relative to the temporary MFN state. $u(\gamma) \equiv \frac{\beta\gamma\lambda}{1-\beta}$ uses $\gamma \equiv 1 - \lambda_{11}$, and $\gamma\lambda = \lambda_{12}$.

To understand the effect of uncertainty in R&D investment, consider under which conditions $U(\gamma,\omega) < 1$. First, firms must face higher tariffs under the worst case scenario compared to the temporary MFN status: $\tau_2 > \tau_1$, as if $\tau_2 = \tau_1$, then $\omega = 1$ and $\varphi_1^U = \varphi_1^D$. Second, $u(\gamma) > 0$, which implies $\gamma > 0$ and $\lambda > 0$: if $\gamma = 0$, then there is no policy uncertainty, and $\varphi_1^U = \varphi_1^D$; if $\lambda = 0$, then tariff increases are not possible, and uncertainty has no impact on R&D investment.

To understand the model implication, and to build a bridge between the theory and the empirical application, let M be the mass of active firms (producing both for the domestic and the export market). The model highlights an extensive margin effect of TPU, whereby more firms find it profitable to innovate when TPU is low or absent: when $U(\gamma,\omega) < 1$, the number of firms that engage in innovative activity increases from $M_1^U = M(1 - G(\varphi_1^U))$ when trade policy is uncertain to $M_1^D = M(1 - G(\varphi_1^D))$ when trade policy uncertainty is resolved. This should translate in an increase in innovative activity observed in the data after 2001, and is the focus of the empirical analysis.

3 Estimation and identification

I use China accession to the WTO and the conferral of Permanent Normal Trade Relations by the US as a quasi-natural experiment to identify the causal effect of TPU reduction on innovative activity. The empirical strategy exploits time-industry-country variation in a triple difference in differences.

3.1 Identification

The economic framework presented in session 2 predicts that the productivity level required to invest in R&D is higher in the presence of uncertainty, and thus more firms are expected find R&D investment profitable when uncertainty about foreign market conditions is reduced. This should translate in an increase in innovative activity observed in the data after 2001, which I measure using patent data.

While the model provides the intuition for one industry, the identification strategy exploits the fact that industries are heterogeneous in the difference between column 2 and MFN tariffs, because tariffs are industry specific. Therefore, industries that are relatively more exposed to TPU before 2001 are expected to have a faster growth in the stock of patents than industries relatively less exposed to TPU when uncertainty is reduced. This is because a larger difference between MFN and column 2 tariffs implies higher profit losses if the US reverts to column 2 tariffs. While the probability of reverting to non-market economy status is the same for all industries, the potential profit losses in this worst case scenario vary across industries, because both MFN and column 2 tariffs vary across industries. I exploit variation in the log difference between MFN and column 2 tariffs across industries as a source of variation to identify the effect or reduced TPU on innovation.

Identifying the effect of interest may be challenging. Simply comparing patenting in Chinese industries exposed to high *vs* low potential profit losses (1^{st} difference), before and after PNTR conferral (2^{nd} difference) may lead to a biased estimate of the effect of interest. This is because there may be other policy changes correlated with both the difference between column 2 and MFN tariffs, and innovation by Chinese industries, that invalidate the common trend assumption. For example, as part of WTO accession, China committed to implement several reforms to liberalize its economy. These include reduction of its import tariff rates, which are bound at an average of 9 percent, removal of restriction on exporting, importing, and barriers to foreign investment. Finally, China's WTO accession coincides with the elimination of quotas for textiles exports under the MFA in 2002 and 2005. Therefore, it is possible that industries exposed to high and low potential losses have different trends in patenting after 2001.

To address this concern, I exploit the richness of the patent data, available for other countries than China, and use time-industry-country variation in a triple difference in differences. Precisely, I construct the change in the log patent stock for each country and industry available in the dataset. The simple difference-in-differences removes time varying trends that are common across industries within the same country. Adding a third difference allows to remove industry-specific trends. Then, I compare patenting growth in industries exposed to high *vs* low potential profit losses (1^{st} difference), before and after PNTR conferral (2^{nd} difference), across countries (3^{rd} difference).

Another potential identification challenge concerns the log difference between column 2 and MFN tariffs, which proxies for potential profit losses if the US does not renew the NTR status. The concern is that column 2 and MFN tariffs may be set by the US to protect industries with declining innovation, and/or industries in which innovation growth and competition is expected from China. Reassuringly, about 80% of the variation in this uncertainty exposure measure is explained by variation in the column 2 tariffs, which were set in 1930 under the Smoot-Hawley Tariff Act, while the average non-NTR is stable around 4% during the 1990-2001 period.

3.2 Empirical model

To compare patenting growth in industries exposed to high *vs* low potential profit losses (1^{st} difference), before and after PNTR conferral (2^{nd} difference), across countries (3^{rd} difference), I estimate the following generalized difference in difference in differences model:

$$\Delta \ln(P_{jnt}) = \alpha + \delta_{nt} + \delta_{jn} + \delta_{jt} + \beta PostPNTR_t \times ln\left(\frac{\tau_{j2}}{\tau_{j1}}\right) \times \mathbb{1}\{s = CN\} + \epsilon_{jnt}, \quad (22)$$

where the dependent variable, $\Delta \ln(P_{jnt})$, is the change in the log stock of granted patents[15] in industry j in country n in period $t = 0, 1$. δ_{nt}, δ_{jn}, and δ_{jt} are country-time, country-industry, and industry-time dummies respectively. $PostPNTR_t$ is a dummy denoting the period after China's WTO accession, $ln(\tau_{j2}/\tau_{j1})$ is the log difference between column 2 and MFN tariffs, and $\mathbb{1}\{n = CN\}$ is an indicator variable equal to one for China, and zero otherwise. The coefficient β identifies the effect of uncertainty, and ϵ_{jnt} is the error term.

The outcome variable $\Delta \ln(P_{jnt})$ is measured as the change in the log cumulative patent stock between 1995 and 2000 or between 2001 and 2007. The patent stock is measured as the cumulative count of patents filed in

[15] I use only patents of inventions, and exclude utility models.

industry j and in period t by all firms resident in country n:

$$P_{jnt} = \sum_{t=1965}^{T} \sum_{i \in \Omega_{jn}} p_{ijnt}, \tag{23}$$

where p_{ijnt} is the number of granted patents filed in industry j and year t by firm i resident in country n; Ω_{jn} is the set of firms in country n filing patents in industry j.

The uncertainty exposure measure is given by the log difference between iceberg-equivalent column 2 tariffs that the US applies to non-market economies, and MFN tariffs that the US offers to WTO members:

$$ln\left(\frac{\tau_{j2}}{\tau_{j1}}\right) = ln\left(\frac{1+T_{j2}}{1+T_{j1}}\right), \tag{24}$$

where T_{2j} and T_{1j} are the *ad-valorem* column 2 and MFN tariff lines respectively, aggregated at the HS 6-digit level. I use the T_{2j} and T_{1j} for 1999,[16] but both MFN and column 2 tariffs for China are stable over the period.[17]

4 Data

4.1 Tariffs

The source of tariff data is the UNCTAD Trade Analysis Information System (TRAINS). I extract average applied MFN and column 2[18] tariff lines disaggregated at 6-digits level of the Harmonized System (HS) for the US. All tariff lines are converted to their iceberg form, so $\tau_j = 1 + T_j$, where T_j is the *ad-valorem* tariff.

There are 4145[19] HS 6-digit industries in the 2002 classification, and for 3811, the growth rate of patenting, $\Delta ln\left(P_{jnt}\right)$, is defined for both the pre- and post-WTO period for China.[20]

[16]In November 1999 the US and China sign the bilateral agreement on China's entry into the WTO.

[17]Note that this uncertainty exposure measure is by definition zero for countries considered by the US as market economies.

[18]Column 2 tariffs are extracted at 8-digit level and converted to 6-digit by taking the simple average of HS 8-digit tariffs within each HS 6-digit product category.

[19]The original data contains 4223 industries. I winsorize this sample by dropping the top and bottom 1% of the $ln(\tau_{j2}/\tau_{j1})$ to avoid using extremely high or low values of $ln(\tau_{j2}/\tau_{j1})$. However, the results are almost identical if the original sample is used.

[20]For this measure to be defined, there needs to be at least one patent application in the HS category in 1995 or earlier.

4.2 Patents

I use patents from PATSTAT[21] to measure industries' innovative activity. PATSTAT contains the population of all patents filed globally since the Mid-19^{th} century, and collects a wide range of information (bibliographic information, family links, citations, etc.) of 100 million patent applications from 90 patent authorities. I observe the name and the address of patent applicants. This allows me to identify the population of all applicants resident in a country in the period of analysis. For each application, I observe the filing date, the publication date, and whether, when, and by which patent authority the patent was granted.

To measure the innovative activity of an industry j in country n in year t, I count patents by application filing year (p_{jt}).[22] I use patent families[23] to identify unique inventions, that is identical inventions filed in multiple locations are not double counted. To ensure that patents by Chinese applicants are comparable in terms of quality and validation procedure to patents in other countries, I only use granted patents of inventions, and exclude utility models. I also use different proxies for patent quality, such as citations, family size, and number of inventors, to take into account the fact that patent quality is highly heterogeneous.

Patents are organized according to their technical features by the International Classification System (IPC), and need to be matched to an industry classification system in order to follow industries' innovative activity over time. I use the Algorithmic Links with Probabilities approach as in Lybbert and Zolas (2014) to match patents to industries. I map IPC 4-digit classes to HS 6-digit industries. For example, a patent on semiconductors (IPC class H01L) is linked to all industries that use semiconductors.[24]

[21] The European Patent Office's (EPO) Worldwide Patent Statistical Database (henceforth PATSTAT), the October 2016 version.

[22] The application filing date is more closely timed with when the R&D process takes place than the publication and grant date. Dating patents by application filing date is the conventional approach in the empirical literature.

[23] I use DOCDB patent family.

[24] One technical class can be matched to more than one industry. To take the goodness of the match into account, and to correct for potential errors in the matching procedure, each patent is weighted by the probability that a technical class is matched to a product category. For example, if a patent with technical class h is matched to HS category j with probability 0.3 and to category k with probability 0.7, HS category j is assigned 0.3 patents, and HS category k is assigned 0.7 patents.

4.3 Descriptives

Figure 1 shows the distribution of $ln(\tau_2/\tau_1)$ for HS 6-digit industries in 1999, which proxies for industruies' differential exposure to uncertainty, and provides the source of variation in the analysis. Table 1 shows mean and standard deviation of $ln(\tau_2/\tau_1)$, the MFN and column 2 tariff lines in 1999. The potential profit loss faced by Chinese industries willing to export to the US market is high on average, and there is considerable variation across industries. The average $ln(\tau_2/\tau_1)$ is 0.25, with a standard deviation of 0.14. It is also worth noting that, while MFN tariff lines are relatively low for all industries, averaging around 0.04, with a standard deviation of 0.05, column 2 tariff lines are very high. The average column 2 tariff is 0.29, with a large standard deviation of 0.16.

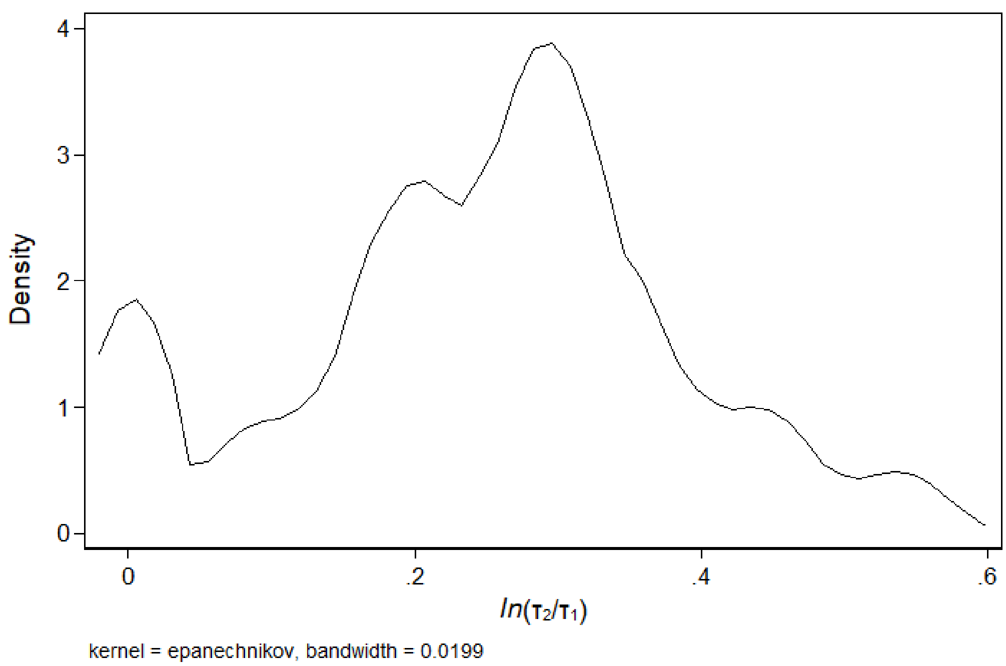

Figure 1: Distribution of $ln(\tau_2/\tau_1)$, 1999.

Table 2 provides summary statistics for patent growth in the period 2001-2007. Industries are divided into two groups based on the potential profit losses if the US revoked the temporary MFN status: industries in the bottom tercile of τ_{j2}/τ_{j1} are classified as facing low potential losses,

	$ln(\tau_{j2}/\tau_{j1})$	$ln\tau_{j2}$	$ln\tau_{j1}$
Mean	0.248	0.287	0.037
St. deviation	0.135	0.156	0.045

Notes: Tariffs are converted to their iceberg equivalent: $\tau = 1 + T$, where$T$ is the *ad-valorem* tariff. τ_1 denotes MFN tariffs, τ_2 denotes column 2 tariffs.

Table 1: Tariffs in 1999

	Profit losses			
	high	low	Total	Difference
Patent growth ($\Delta \ln P$)	1.88	1.77	1.84	0.11
	(0.01)	(0.02)	(0.01)	(0.02)

Notes: Simple means and standard deviations in parentheses. Low prifit losses are defined as the bottom tercile of τ_{j2}/τ_{j1} . $\Delta \ln P$ refers to the period 2001-2007. The mean difference in column 4 is significant at 1%.

Table 2: Descriptives patents

remaining industries are considered as facing high losses. Column 4 shows that industries initially exposed to high potential profit losses have higher patent growth on average, and the difference is statistically significant.

5 Results

I estimate the triple difference model presented in equation (22). The model includes country-time, country-industry, and industry-time dummies, and standard errors are clustered at the country-industry level. I estimate the model using $\Delta \ln(P_{jnt})$ calculated for all countries and industries available in Patstat, and I exclude the US as it could be itself affected by the PNTR shock. Column 1 of Table 3 shows the results for the triple difference in differences estimation. As predicted by the theory, the coefficient on the $PostPNTR_t \times ln(\tau_{j2}/\tau_{j1}) \times CN$ is positive and statistically significant, indicating that industries ex-ante exposed to higher potential losses innovate faster than industies exposed to lower potential losses after uncertainty over US trade policy is eliminated. The estimated coefficient indicates that if potential profit losses increased by one percent in the pre-WTO period, patenting

	ΔlnP_{jnt}	ΔlnP^{C}_{jnt}	ΔlnP^{I}_{jnt}	ΔlnP^{F}_{jnt}
$Post \times \ln\left(\frac{\tau_{j2}}{\tau_{j1}}\right) \times CN$	0.351^{a}	0.703^{a}	0.322^{a}	0.364^{a}
	(0.0578)	(0.218)	(0.0643)	(0.0769)
Observations	388882	247014	372906	388882
Fixed Effects	nt, jt, jn	nt, jt, jn	nt, jt, jn	nt, jt, jn
Control group	$all, noUS$	$all, noUS$	$all, noUS$	$all, noUS$

Standard errors clustered by industry-country in parentheses.
^{c} $p < 0.1$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Table 3: Baseline results, DDD

growth would be 0.35 percent faster in the post 2001 period.
Column 2, 3, and 4 of Table 3 report the result when using quality adjusted measures in the outcome variable. This is to address the fact that patents are highly heterogeneous in quality. I use three proxies for quality that are generally used in the literature: the number of citations, the size of the research team behind a patent, and the patent family size.[25] Patents are then weighted by the number of citations (column 2), the number of inventors (column 3), and the family size (column 4). In this way, higher value inventions receive more weight. The results for these quality adjusted measures confirm the findings in the baseline estimation.

5.1 Robustness

To assess the validity of the empirical strategy, I propose two robustness tests. First I exploit the case of Vietnam, similar to China in the annual renewal of temporary MFN status ($\tau_2 > \tau_1$), but characterized by no uncertainty ($\gamma = 0$) related to the renewal process. Vietnam obtains temporary MFN status in December 2001, after signing a bilateral trade agreement with the US in 2000. As for China, the NTR status is granted by the US president, and is conditional on annual renewal until 2007, when Vietnam becomes a WTO member, and obtains permanent MFN status from the US. Unlike the case of China, however, Congress has never introduced a resolution to revoke Vientam's MFN status, except in 2002, when the resolution is strongly rejected with 332 against 91 votes. Therefore, uncertainty with respect to US trade policy is very low in Vietnam, and the model predicts a

[25] The number of patent applications in the same patent family.

	ΔlnP_{jnt}	ΔlnP_{jnt}
$Post \times \ln\left(\frac{\tau_{j2}}{\tau_{j1}}\right) \times VN$	-0.319	
	(0.277)	
$Post \times \ln\left(\frac{\tau_{j2}}{\tau_{j1}}\right) \times TW$		-0.0376
		(0.0657)
Observations	488814	382392
Fixed Effects	nt, jt, jn	nt, jt, jn
Control group	$all, noUS, noCN$	$all, noUS, noCN$

Standard errors clustered by industry-country in parentheses.
^{c} $p < 0.1$, ^{b} $p < 0.05$, ^{a} $p < 0.01$

Table 4: Robustness

very small no effect of TPU on innovation in Vietnam. To test this prediction, I estimate a similar equation as in 22, using data for the period 2001-2012. The result is shown in column 1 of Table 4, and confirms that there is no significant impact of TPU reduction after Vietnam joins the WTO and obtains permanent MFN status.

Second, I look at the case of Taiwan. Like China, Taiwan joins the WTO in 2002, but unlike China, it has never faced an annual renewal of its MFN status. Therefore, the TPU reduction should have no effect on innovative activity by Taiwanese industries. To confirm this, I estimate the same model as in (22) by using Taiwan instead of China. Column 2 of Table 4 shows the result for equation (22) estimated for Taiwan, and finds no effect of TPU reduction in Taiwan.

6 Conclusion

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A Policy Background

Chinese exports to the US used to be subject to high tariffs that the US reserves to non-market economies until 1980. These tariffs, called 'non-NTR' or 'column 2' tariffs, were set in 1930 under the Smoot-Hawley Tariff Act, and are higher than the tariffs US applies to all other countries. In 1980, the President of the United State granted temporary MFN status to China,[26] and from this moment, annual renewal of China's MFN status kept US effective applied tariffs low. In 2001, as a result of China's WTO accession, US applied tariffs on Chinese imports were permanently set to MFN levels. Renewal of China's MFN status occurred nearly automatically in the first decade. However, after the Tienanmen Square incident in 1989, US Congress introduced and voted on a joint resolution to revoke China's MFN status every year from 1990 to 2001. The need of annual renewal introduced uncertainty over US trade policy. Had the US revoked China's MFN status, US import tariffs would have jumped to the much higher 'non-NTR' rates. The average 'non-NTR' tariff was 34%, while the average applied MFN tariff was 4.6%. Figure 2 shows House of Representatives votes against renewing China's temporary NTR status. For three times, in 1990, 1991, and 1992, the House voted against renewal, but China didn't lose MFN status because of the lack of support by the US Senate.
With accession to WTO in 2001, China obtained permanent normal trade relation status (PNTR). This set US import tariffs to MFN levels permanently, and thus ended the threat of potential tariff increases and uncertainty on US trade policy.

[26]Under the US Trade Act of 1974, the President of the United States has the right to grant temporary MFN status to non-market economies.

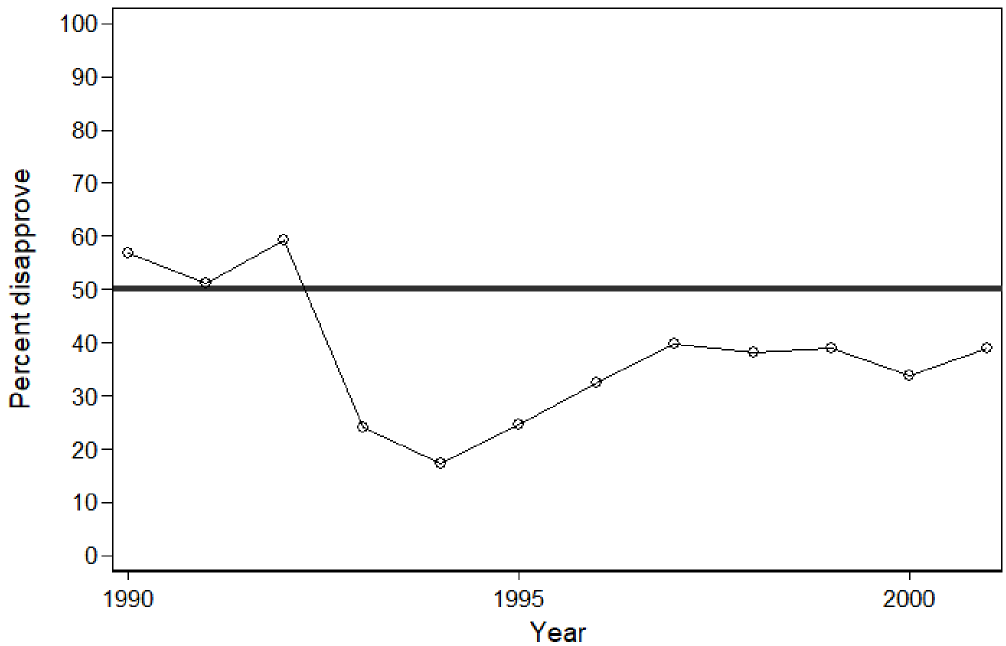

Figure 2: House votes to renew China's temporary NTR status (1990-2001).

Source: Own calculation using Pierce and Schott (2016) data.

B Mathematical derivations

B.1 Productivity cutoff

Using the expressions for domestic and export profits, the innovation indifference condition (9) gives the productivity cutoff in the benchmark deterministic case:

$$B_d(\eta\varphi_s^D)^{\sigma-1} - B_d(\varphi_s^D)^{\sigma-1} + B_x\tau_s^{-\sigma}(\eta\varphi_s^D)^{\sigma-1} - B_x\tau_s^{-\sigma}(\varphi_s^D)^{\sigma-1} = K(1-\beta) \quad (25)$$

$$\iff \varphi_s^D = \left(\frac{I(1-\beta)}{(\eta^{\sigma-1}-1)(B_d + B_x\tau_s^{-\sigma})}\right)^{\frac{1}{\sigma-1}}$$

Consider now a firm in the intermediate state, $s = 1$, with MFN tariffs subject to annual renewal. The productivity threshold with uncertainty is given by the solution to the Bellman equation in (10). By rewriting the Bellman as in (14), the marginal firm has

$$
\begin{aligned}
V_s\left(\varphi_s^U\right) &= 0 && (26)\\
&= \max\{0, \beta \mathbb{E}_s V_s'\left(\varphi_s^U\right) - \left[\pi_d(\eta\varphi_s^U) - \pi_d(\varphi_s^U)\right] - \left[\pi_x(\tau_s, \eta\varphi_s^U) - \pi_x(\tau_s, \varphi_s^U)\right] \\
&\qquad + (1-\beta)I\}, && (27)
\end{aligned}
$$

and the cutoff productivity level φ_s^U is found by equating the second element in the curly bracket to zero. Starting at the intermediate policy state, $s = 1$, and replacing π_x and π_d with the equations (1) and (2) in **??**, the productivity cutoff in the intermediate state is given by

$$
\begin{aligned}
\varphi_1^U &= \left(\frac{I(1-\beta)}{(\eta^{\sigma-1}-1)\left(B_d + B_x \tau_1^{-\sigma} \frac{1+u(\gamma)\omega}{1+u(\gamma)}\right)} \right)^{\frac{1}{\sigma-1}} && (28)\\
&= \left(\frac{I(1-\beta)}{(\eta^{\sigma-1}-1)\left(B_d + B_x \tau_1^{-\sigma} U(\gamma,\omega)\right)} \right)^{\frac{1}{\sigma-1}} \\
U(\gamma,\omega) &\equiv \frac{1+u(\gamma)\omega}{1+u(\gamma)} && (29)
\end{aligned}
$$