CESifo WORKING PAPERS

10253
2023

January 2023

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CESifo

Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
Editor: Clemens Fuest
https://www.cesifo.org/en/wp
An electronic version of the paper may be downloaded
· from the SSRN website: www.SSRN.com
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CESifo *Working Paper No. 10253*

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Abstract

We develop a dynamic model of inventory investment and trade to examine how firms adjust to changes in international trade costs when facing a risk of stockouts due to demand uncertainty and order lead times for imports. We study two strategies firms may use to avoid stockouts, namely holding inventories of imports, and engaging in dual sourcing. Both strategies are shown to magnify the protective effects of trade costs. Using transaction-level data for a U.S. steel wholesaler experiencing an episode of Section-201 tariffs, we find strong evidence consistent with this magnification effect. Higher tariffs are shown to significantly reduce both the inventory-sales and the import-sales ratios, as the firm adjusts its stockout avoidance strategies.

JEL-Codes: F120, L810.

Keywords: international trade, import tariff, inventory, dual sourcing, stockout avoidance.

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January 19, 2023
We would like to thank Peter Egger, Dennis Novy and audiences at the CESifo Area Conference on Global Economy, the Aarhus-Kiel Workshop, the Göttingen Workshop for helpful comments and suggestions. We would also like to thank Max Cojahmetov, Jasleen Grewal, Gigi Lin and Brandon Wong for their research assistance. Financial support from SSHRC (Grant 435-2016-0354) and from the SFU VPR USRA program is gratefully acknowledged.

1 Introduction

Firms facing uncertain demand respond to a demand shock by adjusting price and/or quantity. Adjusting quantity critically depends on how fast production can react to a shock and how long shipments take to reach buyers. Lead time is particularly important for international markets especially when shipping time between continents can easily take three weeks or more, and when international shipping is hit by port bottlenecks and shipping lane disruptions as witnessed over recent years. Long lead times call for strategies on the part of the firms to mitigate their impacts. They range from choosing locations of production closer to consumers, diversifying the sourcing of goods, to choosing additional modes of transportation. For instance, if it takes significant time to receive an order by sea shipping, a firm could respond to a demand surge by air shipping some units. This is more expensive but it is often a better response to a demand surge than having to forego sales. The same is true with domestic sourcing when it is normally cheaper to source abroad.

Several of these strategies have been investigated theoretically and documented empirically (see more on this below), but they are mostly coming from a just-in-time production perspective. Inventory adjustments, the traditional method to respond to demand uncertainty, are often disregarded presumably because firms are thought to have a high willingness to pay for fast delivery in comparison to the cost of holding inventory. There are several reasons why this may be true. Product differentiation, in particular, typically leads to a rapid churning of goods as they quickly may become less fashionable or even obsolete, making holding inventory unattractive as compared to alternative strategies. But there is a large range of products, for instance, those that are more homogenenous, for which this is much less the case. In addition, the disruptions and demand shocks created by COVID-19 have taught many firms that holding inventory is a much more desirable strategy than previously thought. Thus, it is important to refocus on inventory considerations as a central part of a firm's strategy for mitigating the impact of demand uncertainty. However, this does not need to be at the expense of some of these other strategies, especially as there is evidence that they are not mutually exclusive. This paper explores this issue in a theoretical model, and proposes empirical tests of some of its implications.

Hence this paper should be seen as placing inventory considerations back at the centre of a firm's strategy in an environment with demand uncertainty and long lead times, and investigating how this affects the impact of changes in international trade costs. We believe that such an exercise is important in light of observations over the last few years of an increase in demand uncertainty, significant changes in international shipping costs, and more active trade policy.[1]

Specifically, the purpose of the current paper is twofold. First, we propose a simple and original dynamic model capturing how firms adjust their inventory and sourcing strategies in response to changes in international trade costs, what role demand uncertainty plays for this adjustment, and what the consequences are for the volume of imports. Second, we seek direct, micro-level empirical evidence of these adjustments in action and, specifically, of the mechanisms that drive firms' import responses in order to confirm our main theoretical predictions. To our knowledge, this paper is the first to use product-level inventory data to better understand the firm's response to changes in trade costs.

In the model we consider two ways in which an importer may reduce the risk of stockouts when importing involves an order lead time and demand is uncertain, namely (i) building up the inventory of imported goods, and (ii) relying on dual sourcing, i.e., using more expensive, but quickly available domestic supplies to cover demand surges. Our model builds on Reagan (1982) who characterizes the solution to a dynamic programming problem, in which a monopolist facing demand uncertainty maximizes the discounted present value of its profit stream. In this framework, we show that stockout avoidance has three main implications for the effects of a trade cost change. First, in response to a temporary or permanent increase in trade costs, the firm typically reduces its inventory by more than expected sales. The reason is that an increase in trade costs induces the firm to adjust its stockout avoidance strategy either by accepting a greater stockout probability (if domestic substitutes are sufficiently expensive), or by changing its dual sourcing mix toward greater domestic sourcing (if domestic substitutes are not too expensive). Second,

[1]For instance, UNCTAD (2020) lists 18 broad sectors out of a total of 25 for which the average tariff is higher in 2019 than in 2010. Globaltradealert.com reports respectively 4,967 and 3,279 harmful trade policy changes worldwide in 2020 and 2021 against an average of about 2,500 per year during the period 2009-19. Of course many of the 2020-21 ones originated in the US and China. Demand uncertainty is more difficult to measure but it is difficult to deny that we are in an age of volatility. For instance, the World Uncertainty Index tends to spike when there are crises like COVID-19, the Brexit vote or wars (Ahir et al.. 2022). Finally, the Statista Global container freight rate index rose from about \$2,000 in August 2020 to a peak of \$10,300 in September 2021. It is now (Nov. 2022) almost back to \$2,000 (https://www.statista.com/statistics/1250636/global-container-freight-index/).

these changes in the firm's stockout avoidance strategy imply that the firm reduces its imports by more following a temporary and/or permanent increase in trade costs than in situations in which it does not engage in stockout avoidance. Hence the impact of a change in trade costs is magnified in an environment in which the firm adjusts its inventory and sourcing strategies to avoid stockouts. Third, an increase in demand uncertainty further boosts the negative effect of an increase in trade costs on inventory and on the expected import volume.

We examine the empirical relevance of our model and, specifically, of the stockout avoidance mechanisms by testing some of the key predictions using data on inventories, sales transactions, as well as domestic and foreign purchase transactions of nearly 1,800 different steel products by an anonymous U.S. steel wholesaler over a period starting in 2001 and ending in 2004. There are four reasons why this specific data set is particularly useful to study inventory adjustments, dual sourcing and changes in trade cost. First, the period includes a trade cost shock in the form of Section-201 tariffs introduced by the Bush Administration on imports of 272 separate 10-digit HS steel products between March 20, 2002 and December 4, 2003. This shock is ideal for identification, as the shock is exogenous to the firm and affects only a subset of the products carried by the firm. Second, domestic and foreign purchases are recorded separately, and dual sourcing is indeed observed for many products. Third and most importantly, our inventory data are available at the product level which is the level of detail required to trace the effects of product-specific tariffs. Fourth, our data come at high enough frequency—up to a daily record of transactions—to study the mechanisms behind stockout avoidance, not least changes in the frequency of stockouts.

Our empirical analysis provides robust support for the stockout avoidance mechanisms studied in the model. In particular, we find that the imposition of the steel tariffs has both statistically and quantitatively significant effects on the inventory-sales and the import-sales ratios, driven by an increase in the stockout probability and a shift in the firm's dual sourcing mix. For instance, the tariff reduces the mean inventory-sales ratio by 65% for products hit by a 30% tariff, whereas the import-sales ratio falls by 51% on average. We also find evidence for the model's prediction that demand uncertainty boosts the effect of tariff protection, as products experience a significantly larger decrease in inventory when hit by a 30% tariff the greater is the product-specific level of demand uncertainty.

Our paper contributes to a better understanding of the effects of changes in trade costs at the firm level. It is most closely related to the international trade literature analyzing how firms can mitigate the impact of demand uncertainty through strategies including sourcing decisions (Aizenman, 2004; Evans and Harrigan, 2005; Hummels and Schaur, 2010, 2013). Our dual sourcing mechanism is similar to various mechanisms analyzed in this literature, but none of these papers considers inventory as part of a stockout avoidance strategy. By explicitly modelling inventory decisions, along with dual sourcing, we show circumstances under which both strategies are used by importers. Moreover, we show that both strategies offer empirically relevant margins of adjustment to import tariffs.

While we study at the micro level how importers deal with demand uncertainty and delivery lags on imports, and how they adjust their inventory and sourcing strategies when exposed to a trade-cost change, Carreras-Valle (2021) takes a more macro view to examine how U.S. manufacturers adjust their inventory position when sourcing an increasing share of intermediate goods from China. By calibrating a stochastic general equilibrium model where shipments are subject to long and stochastic delivery times, she shows that increased sourcing from China explains a significant part of the observed increase in U.S. manufacturing inventories since 2005.

Our paper is more indirectly related to Kropf and Sauré (2014). Although they model inventory investment by importing firms, they do so in a framework with deterministic demand where the motive for holding inventory is to save on fixed costs per shipment. In fact, Kropf and Sauré seek to quantify these fixed costs per shipment. In our model, by contrast, the firm holds inventory to avoid stockouts in the face of demand uncertainty, and we study how stockout avoidance shapes the effects of changes in trade costs. In particular, we seek to study and to quantify two adjustment mechanisms, namely an inventory adjustment reflected by a change in the stockout probability, and a change in the dual sourcing mix.[2]

The current paper also contributes to the literature on international trade policy, since an important goal of the paper is to understand how inventory influences the impact of barriers to trade such as tariffs or international transport costs in the presence of demand uncertainty. The source of uncertainty is thus not with trade policy as in Crowley et al. (2018), Feng et al. (2017), Handley and Limão (2017, 2015), or Handley et al. (2020). We

[2]Békés et al. (2017) study how firms adjust the frequency and size of shipments in response to demand volatility on their export market. They argue that the observed adjustments could be rationalized by a stochastic inventory model.

see our setup with demand uncertainty as a natural first step when considering inventory investment and international markets. Our paper is indirectly related to Khan and Khederlarian (2021) who study the effect of anticipated trade policy changes on short-run import dynamics. They argue that import slumps ahead of anticipated tariff reductions followed by import surges after these tariff reductions have come into effect are consistent with importer inventory adjustments. By contrast, our paper shows how stockout avoidance may lead to structural adjustments in inventory and imports in response to temporary or permanent trade cost changes.

The stockout avoidance motive for holding inventory has been studied extensively in economics and operations management following seminal papers by Arrow et al. (1951), Bellman et al. (1955), and Scarf (1959). More recently, it has been used as a way to rationalize important empirical observations that cannot easily be reconciled with alternative inventory models (see, for instance, Kahn (1987, 1992, 2000), Blinder and Macchini (1991)). In the international macroeconomics literature, in particular, stockout avoidance has been shown to explain aggregate trade dynamics following shocks such as large devaluations or the world financial crisis (Alessandria et al., 2010a, 2010b; Novy and Taylor, 2020).[3] Our approach is different from theirs and thus complements it. In particular, by focusing on specific firm-level mechanisms behind inventory adjustments to trade cost changes, we are able to provide direct, micro-level evidence for these mechanisms.

In the next section, we propose a simple dynamic model of inventory investment and dual sourcing that we use in Section 3 to examine how changes in trade costs and demand uncertainty affect inventory investment, the probability of a stockout and domestic sourcing, as well as the volume of imports. Section 4 contains a description of the data, and our empirical analysis is in Section 5. Section 6 concludes. In the appendix, we collect proofs of our results and provide additional results from the model.

[3]There are, of course, many papers in the operations management literature that consider optimal inventory investment and dual sourcing strategies to hedge demand uncertainty (see, for instance, Allon and Van Mieghem (2010), Jain et al. (2014), and Boute and Van Mieghem (2015)). But these papers generally do not examine the effects of trade policy. Note that dual sourcing in the sense that we use it, namely ordering the same input from an inflexible but cheap and from a flexible but expensive source to hedge demand uncertainty, is different from "multi-sourcing" analyzed, for instance, by Gervais (2018). Multi-sourcing in Gervais (2018) refers to risk-averse firms sourcing the same input from multiple suppliers to hedge idiosyncratic supply shocks, but firms are assumed not to hold any inventory.

2 Model

In this section we develop a dynamic inventory model to study how an importer responds to changes in trade costs when importing involves a one-period time lag between order and delivery, and demand is uncertain. The time lag implies that imports are exclusively to inventory and cannot be used to satisfy contemporaneous demand. Demand uncertainty implies that the importer has to decide how much inventory to hold to avoid stockouts. It is key in what follows to realize that, in this setting, imports are not driven by contemporaneous demand, as would be the case in a static model, but rather by the importer's decision of how much future inventory to hold. The importer's optimal level of future inventory in turn depends not only on expected future demand but, importantly, also on how it chooses to deal with the risk of stockouts.

In each period t, the importer faces a linear inverse demand $p_t = a + \epsilon_t - bq_t$ for its product, where p_t and q_t denote price and sales in period t, respectively, ϵ_t is an i.i.d. random shock uniformly distributed on $[-\Delta, \Delta]$, and $\Delta < a$ holds such that the random shock is small relative to the size of the market. For each unit sold, the firm needs one unit of an input good that can be either imported or sourced domestically.[4] Domestic sourcing is immediate in the sense that domestic goods can be ordered and delivered after the demand in that period has been revealed; hence we may think of domestic orders as involving just-in-time delivery. The domestic order in period t is associated with the domestic unit cost w_t and quantity y_t. Importing is inflexible, because it takes one period for goods to be delivered; orders for imports therefore have to be placed before the realization of demand is known. In particular, an import purchase made (and paid) in period $t-1$, at the foreign unit cost v_{t-1} and involving a quantity denoted by m_{t-1}, can only be used in production in period t or later. For now, it is convenient to interpret the foreign unit cost as including the purchase price as well as trade costs, such as tariffs, transportation costs and other variable transaction costs involved in purchasing the input; we will consider the example of a tariff in the empirical analysis.

[4]If the importer is a wholesaler, it just sells the goods it has in inventory. If the importer is a manufacturer, the input good is an intermediate input that is transformed into output one for one, where we abstract from possible substitutability between the intermediate input and other inputs, such as labor. Our model could easily accommodate labor and other inputs, especially if these are perfect complements to intermediates. For example, if producing a unit of output also requires l units of labor, so that the unit labor cost is given by $c = l\omega$, where ω denotes the wage, we can simply define the new demand intercept as $a = A - c$ where A is the original demand intercept.

Since imported goods available in period t were not ordered in the same period as domestic goods available in that period, we take into account the discount factor $\delta < 1$, so that the appropriate comparison of the two input costs is between w_t and v_{t-1}/δ. We consider the case where imports are cheaper than domestic goods (i.e., $v_{t-1}/\delta \leq w_t$). The trade-off between them is clear: imports are cheap but the firm has to place orders before demand is known, and they can only be used in production next period, whereas domestic goods are expensive but arrive 'immediately' in the sense that an order can be placed and received once current demand is known.[5]

In any period, the firm may end up not using the entire quantity of goods that it purchased. We denote the volume of these unsold units in period $t-1$ by z^0_{t-1} and they become part of the available inventory to be used in t. We refer to z^0_{t-1} as *excess inventory* in period $t-1$. We refer to z_t as *inventory* in period t and define it as the volume of goods available for use at the beginning of the period.[6] Thus inventory is equal to $z_t = m_{t-1} + z^0_{t-1}$, that is, the sum of imports purchased in period $t-1$ and arriving at the beginning of period t, and the excess inventory inherited from period $t-1$. We assume that z^0_{t-1} is known when the firm chooses m_{t-1}.[7]

In each period t, the importer maximizes the discounted sum of expected future profits by choosing sales, q_t, the quantity sourced domestically, y_t, and the quantity of imports m_t to be delived in period $t+1$. We follow Reagan (1982) in deriving the optimal solutions by formulating a dynamic programming problem. To make this programming problem tractable in the sense of obtaining closed-form solutions suitable for studying the effects of trade cost changes, we make two mild simplifying assumptions. First, we assume that

[5]Our analysis could also accommodate the case where w_t is not known in $t-1$, but is the expected domestic cost. Then it may happen that the realized w_t is smaller than v_{t-1}/δ. We could also endogenize w_t and v_{t-1} by assuming that they are set by (or negotiated with) upstream producers with market power. Qu et al. (2018) examine vertical price and inventory externalities arising under different downstream market structures in an intertemporal inventory model.

[6]Notice that we implicitly assume that the firm only holds inventory of intermediate goods. This makes sense for a firm like our steel wholesaler who carries out very little transformation of inputs into output. A manufacturer, however, would typically also hold inventory of goods in process or of finished goods. If the purpose of holding inventory is to hedge demand uncertainty, it would not matter in which form this inventory is held. Thus the model could be extended to include a production process that allows for different forms of inventory from intermediate to finished goods.

[7]This implies that, when an import order is placed, the firm knows the realization of the demand of the current period. If orders were placed before z^0_{t-1} is known, then $m_{t-1} = z_t - E(z^0_{t-1})$, where $E(z^0_{t-1})$ is the expected excess inventory.

m_t is chosen after q_t and y_t have been set; hence it is only the choice of m_t that affects expected future profits, while q_t and y_t only affect contemporaneous profit. Second, as made explicit below, we assume that the firm does not build up excessive inventories so that $m_t > 0$ for every t. The Bellman principle of optimality then implies that, given that the importer optimally chooses q_t and y_t, and makes optimal decisions on q_{t+1}, y_{t+1}, m_{t+1} and likewise in all periods after $t+1$, the optimal choice of m_t has to equate the marginal cost in period t with the expected marginal revenue in $t+1$.

Let us therefore consider how the importer chooses q_t, y_t, and m_t. It must be clear from above that, at the beginning of period t, the cost of the foreign inputs ordered in $t-1$ is sunk. The cost of ordering domestic goods in period t is avoidable. Thus, a firm always prefers selling its entire available inventory before buying domestically so that, in any period t, it faces three possibilities: (i) it sells less than its inventory z_t and does not order domestically; (ii) it sells its entire inventory z_t but does not order domestically; or (iii) engages in dual sourcing, i.e., it sells its entire inventory z_t and buys, as well as sells, y_t domestically.

If the firm does not sell all of its inventory z_t, it values each unit of the excess inventory z_t^0 that the firm takes into period $t+1$ at its opportunity cost; that is, at the cost to import it for delivery in $t+1$, v_t, minus the cost of storing it, denoted by $\gamma \geq 0$, provided that $v_t \geq \gamma$. Denoting the opportunity cost by ρ_t, we have $\rho_t = \max\{0, v_t - \gamma\}$. If $v_t < \gamma$, the firm does not accumulate excess inventory, but rather discards any unsold units. We assume that $\rho_t < v_{t-1}/\delta \leq w_t$. Thus, the firm places a positive value on unsold units, but this value is not so high that it would voluntarily accumulate excess inventory.

We can now characterize the within-period decisions on sales and dual sourcing for a given inventory z_t. The firm's profit in period t, denoted by $\pi_t(q_t)$, is given by

$$\pi_t(q_t) = \begin{cases} (a + \epsilon_t - bq_t)q_t + \rho_t(z_t - q_t) & \text{if} \quad q_t \leq z_t, \\ (a + \epsilon_t - bq_t)q_t - w_t(q_t - z_t) & \text{if} \quad q_t > z_t, \end{cases} \tag{1}$$

implying optimal sales

$$q_t^*(\epsilon_t) = \begin{cases} \frac{a+\epsilon_t-\rho_t}{2b} & \text{if} \quad \frac{a+\epsilon_t-\rho_t}{2b} \leq z_t, \\ z_t & \text{if} \quad \frac{a+\epsilon_t-w_t}{2b} < z_t < \frac{a+\epsilon_t-\rho_t}{2b}, \\ \frac{a+\epsilon_t-w_t}{2b} & \text{if} \quad \frac{a+\epsilon_t-w_t}{2b} \geq z_t. \end{cases} \tag{2}$$

Eq. (2) shows that demand, and thus optimal sales, must be high enough relative to available inventory z_t before the firm buys domestically, simply because the marginal revenue has to exceed the domestic unit cost. If it does not, the firm sells at most its available inventory depending on the comparison between the marginal revenue of using one unit now and the value of holding on to it, ρ_t. Not surprisingly, the lower is ρ_t, the greater is the incentive to sell this unit today. Hence, a lower ρ_t and a higher domestic unit cost w_t imply a wider range of inventory levels over which the importer decides at time t to limit its sales to its entire available inventory, i.e., to *voluntarily* stock out without purchasing any domestic units.

From (2), we can derive the critical demand realizations for which the importer is indifferent between selling all inventory or not, $\underline{\epsilon}(z_t)$, and for which it is indifferent between buying an additional unit domestically or not, $\overline{\epsilon}(z_t)$:

$$\underline{\epsilon}(z_t) = 2bz_t - a + \rho_t, \quad \overline{\epsilon}(z_t) = 2bz_t - a + w_t, \tag{3}$$

with $\underline{\epsilon}(z_t) < \overline{\epsilon}(z_t)$ from our earlier assumptions. Thus, (2) can be rewritten as:

$$q_t^*(\epsilon_t) = \begin{cases} \frac{a+\epsilon_t-\rho_t}{2b} & \text{if} \quad \epsilon_t \leq \underline{\epsilon}(z_t), \\ z_t & \text{if} \quad \underline{\epsilon}(z_t) < \epsilon_t < \overline{\epsilon}(z_t), \\ \frac{a+\epsilon_t-w_t}{2b} & \text{if} \quad \epsilon_t \geq \overline{\epsilon}(z_t). \end{cases} \tag{4}$$

Eq. (4) is useful for three reasons. First, it makes clear that the firm's sourcing strategy depends on demand realizations. Demand can be: (i) low enough so that the firm does not sell its entire inventory and therefore accumulates excess inventory, $z_t - q_t^*(\epsilon_t)$, that it may use next period; (ii) in an intermediate range such that it sells its entire inventory, $q_t^*(\epsilon_t) = z_t$, but does not order domestically; or (iii) high enough that it engages in dual sourcing, i.e., sells goods from both foreign and domestic sources. In the latter case, the purchase of domestic goods is equal to:

$$y_t^*(\epsilon_t) = \frac{a + \epsilon_t - w_t}{2b} - z_t. \tag{5}$$

Second, (4) makes clear that, in order for a firm to effectively face these three options, the realizations of demand must be feasible given the support $[-\Delta, \Delta]$. In particular, (4) is consistent with $[-\Delta, \Delta]$ provided that $-\Delta < \underline{\epsilon}(z_t) < \overline{\epsilon}(z_t) < \Delta$ which, using (3), requires that $\overline{\epsilon}(z_t) - \underline{\epsilon}(z_t) = w_t - \rho_t < 2\Delta$. Hence, given w_t and ρ_t, (4) requires a relatively high degree of demand uncertainty.

Third, it makes it easy to characterize graphically the possible cases that may arise. Figure 1, where $[\underline{\epsilon}(z_t), \overline{\epsilon}(z_t)]$ is fully contained in $[-\Delta, \Delta]$, illustrates the possible realizations of demand consistent with (4). If demand uncertainty is low as in Figure 2, however, and thus if $[-\Delta, \Delta]$ is fully contained in $[\underline{\epsilon}(z_t), \overline{\epsilon}(z_t)]$, then the firm's optimal sales can only be $q_t^*(\epsilon_t) = z_t$ irrespective of the realization of demand.

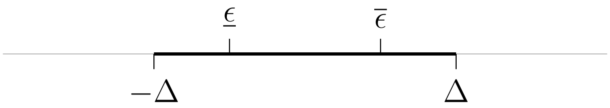

Figure 1: High demand uncertainty

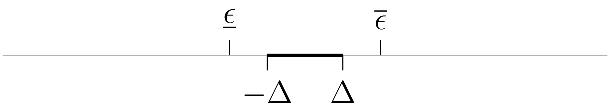

Figure 2: Low demand uncertainty

We can now proceed to the determination of the optimal imports. It turns out to be convenient to characterize the optimal m_{t-1} instead of m_t. This simplifies notation a bit without affecting the optimal intertemporal trade-off. Denoting the optimal imports in $t-1$ by m_{t-1}^*, it is clear that m_{t-1}^* is simply the difference between the desired level of inventory in period t, z_t^*, and the excess inventory in $t-1$, z_{t-1}^0, i.e., $m_{t-1}^* = z_t^* - z_{t-1}^0$. Hence, to obtain m_{t-1}^* we have to determine z_t^*.

Consider, for example, the case in which the importer's expected marginal revenue in period t is consistent with the optimal sales q_t^* as given by (4) and thus for realizations of demand consistent with Figure 1. The expected marginal revenue in period t, $E[MR_t]$, from a unit imported in period $t-1$ is then equal to:

$$\delta E[MR_t] = \delta \left[\int_{-\Delta}^{\underline{\epsilon}(z_t)} \rho_t \frac{d\epsilon_t}{2\Delta} + \int_{\underline{\epsilon}(z_t)}^{\overline{\epsilon}(z_t)} (a + \epsilon_t - 2bz_t) \frac{d\epsilon_t}{2\Delta} + \int_{\overline{\epsilon}(z_t)}^{\Delta} w_t \frac{d\epsilon_t}{2\Delta} \right]. \tag{6}$$

The marginal revenue is equal to ρ_t for low demand realizations ($-\Delta \leq \epsilon_t \leq \underline{\epsilon}(z_t)$) and thus when the firm holds on to units for the next period; it is equal to $a + \epsilon_t - 2bz_t$

when the entire inventory z_t is used; and is equal to w_t when the demand realizations are sufficiently high ($\bar{\epsilon}(z_t) \leq \epsilon_t \leq \Delta$) that purchasing domestically is required.

Using (3) to evaluate (6), equating the outcome to the foreign unit cost v_{t-1}, and solving for z_t, we can compute the optimal inventory $z^*_{t,123}$, where the subscript 123 indicates that we are in regime (123). In regime (123) all three ranges of demand realizations are feasible: accumulating excess inventory due to a low demand realization (labeled range 1); stocking out, that is, using up total inventory but without any domestic sourcing (labeled range 2); and using up total inventory but avoiding a stockout by sourcing additional goods domestically (labeled range 3). Hence $z^*_{t,2}$ (valid for $\underline{\epsilon}(z^*_{t,2}) < -\Delta$ and $\bar{\epsilon}(z^*_{t,2}) > \Delta$) is the optimal inventory in regime (2) when it is always entirely used up and no domestic sourcing takes place, which is the regime illustrated by Figure 2. But notice that the regimes illustrated by Figures 1 and 2 are just two possible outcomes among several that we have to examine. Thus, $z^*_{t,23}$ (valid for $\underline{\epsilon}(z^*_{t,23}) < -\Delta < \bar{\epsilon}(z^*_{t,23}) < \Delta$) refers to the optimal inventory in regime (23), where it is always fully used but some demand realizations require domestic sourcing; $z^*_{t,12}$, valid for $-\Delta < \underline{\epsilon}(z^*_{t,12}) < \Delta < \bar{\epsilon}(z^*_{t,12})$, is the optimal inventory in regime (12) where domestic sourcing never takes place and where the available inventory might not be entirely used.

We have relegated the details of these computations to Appendix A.1 and summarize all optimal inventory levels in the following lemma:

Lemma 1. *1. The feasible optimal inventory levels are:*

$$\begin{aligned} z^*_{t,123} &= \frac{2a - (w_t + \rho_t)}{4b} + \frac{\Delta(w_t + \rho_t)}{2b(w_t - \rho_t)} - \frac{\Delta v_{t-1}/\delta}{b(w_t - \rho_t)}; \\ z^*_{t,2} &= \frac{a - v_{t-1}/\delta}{2b}; \quad z^*_{t,12} = \frac{a + \Delta - \rho_t - 2\sqrt{\Delta\left(v_{t-1}/\delta - \rho_t\right)}}{2b}; \\ z^*_{t,23} &= \frac{a - w_t - \Delta + 2\sqrt{\Delta(w_t - v_{t-1}/\delta)}}{2b}. \end{aligned}$$

2. The conditions under which $z^*_{t,2}$ and $z^*_{t,123}$ are obtained are mutually exclusive.

3. Two inventory levels are not feasible: $z^*_{t,1}$ and $z^*_{t,3}$.

Proof. See Appendix A.1. □

Two comments are in order. First, two regimes never arise: $z^*_{t,1}$ when inventories always exceed needs (requiring $\underline{\epsilon}(z^*_{t,1}) > \Delta$), and $z^*_{t,3}$ involving systematic domestic sourcing irrespective of demand realizations (requiring $\bar{\epsilon}(z^*_{t,3}) < -\Delta$). The former would imply a permanent excess inventory build-up, which is not an equilibrium strategy in our model: a firm never systematically chooses to order so much from abroad that it would accumulate excess inventory for any demand realization. The latter would imply that a firm always sources at least some inputs at home for any demand realization, even if $v_{t-1}/\delta < w_t$.[8] Second, the conditions under which $z^*_{t,123}$ and $z^*_{t,2}$ hold are mutually exclusive because they depend only on the comparison of the degree of uncertainty (2Δ) with $(w_t - \rho_t)$, with $z^*_{t,123}$ requiring $2\Delta > w_t - \rho_t$, and $z^*_{t,2}$ requiring $2\Delta < w_t - \rho_t$.

The optimal inventory levels in the different regimes have a simple interpretation. Namely, in each regime, the firm finds it optimal to hold a level of inventory at the beginning of period t that allows it to realize what it expects to be the profit-maximizing sales. Denoting expected sales by $\hat{q}_t$, we can prove

Lemma 2.

1. *In all regimes, the expected sales in period t are given by*

$$\hat{q}_t = \frac{a - v_{t-1}/\delta}{2b}. \tag{7}$$

2. *The optimal inventory satisfies $z^*_{t,2} = \hat{q}_t$; $z^*_{t,12} > \hat{q}_t$; $z^*_{t,23} < \hat{q}_t$; $z^*_{t,123} \lesseqgtr \hat{q}_t$.*

Proof. See Appendix A.2. □

In each regime, expected sales $\hat{q}_t$ are thus equivalent to the profit-maximizing sales of a firm that does not face any demand uncertainty, relies only on imports and can purchase these imports at the foreign unit cost, v_{t-1}/δ. Why the firm holds enough inventory to realize $\hat{q}_t$ is easiest to see in regime (2), in which the firm always chooses to stock out, i.e., to sell all inventory at hand and not engage in dual sourcing. The firm thus imports in each period the quantity it expects to sell in the subsequent period; hence it starts period t with an inventory that satisfies $z^*_{t,2} = \hat{q}_t$. In regime (12), the firm's optimal inventory exceeds its expected sales, $z^*_{t,12} > \hat{q}_t$ as this is the regime in which there is a positive probability that the firm has excess inventory at the end of a period. In other words, in this regime the firm finds it optimal to carry an inventory of imported goods that exceeds

[8] In Appendix A.1, we show that domestic sourcing is the only source (i.e. $z^*_{t,3} = 0$) if $v_{t-1}/\delta > w_t$.

the quantity it expects to sell, because this allows it to reduce the probability of stocking out and losing sales. In regime (23), $z^*_{t,23} < \hat{q}_t$ so that the firm holds less in inventory than it expects to sell. The reason is that it turns to dual sourcing and thus to domestic supply with positive probability. Finally, it comes as no surprise that in regime (123), where we encounter a combination of the above cases, the optimal inventory at the start of period t may exceed or fall short of expected sales, $z^*_{t,123} \lesseqgtr \hat{q}_t$. We show in the next section, among other things, how these different regimes depend on the level of trade cost.

3 Effects of Changes in Trade Costs and in Demand Uncertainty

We are now ready to determine how a change in the trade cost affects (i) the firm's optimal inventory and import volume relative to expected sales, (ii) the stockout probability, and (iii) the likelihood of engaging in dual sourcing. We also want to examine what a change in the level of demand uncertainty implies for the impact of the trade cost change on the firm's optimal inventory and imports.

The model is flexible enough to allow us to consider two different scenarios for trade cost changes, namely a temporary change, and a permanent change.[9] To avoid cluttering up the analysis we focus here on the effects of a temporary change in $t-1$, and we show only the case of low demand uncertainty. We explain in Appendix A.5 that the effects of a temporary trade cost change are essentially unchanged in the case of high demand uncertainty. Furthermore, we show in Appendix A.6 that a permanent change in the trade cost has qualitatively the same effects as a temporary change for both low and high demand uncertainty.

A temporary trade cost change corresponds to a change in v_{t-1}, but leaves v_t and thus the value of excess inventory in the subsequent period, ρ_t, unaffected. Depending on the magnitude, a temporary change in the trade cost may lead to a change in regime. To see this, notice that $\overline{\epsilon}(z_t) - \underline{\epsilon}(z_t) = w_t - \rho_t$ is independent of v_{t-1}, but $\overline{\epsilon}(z_t)$ and $\underline{\epsilon}(z_t)$ both depend on v_{t-1} through z_t. In particular, given (3), we have:

[9] We can also study the effects of anticipated tariff changes. We do not report the results here, since we do not pursue anticipated tariffs further in our empirical analysis. Results are available from the authors upon request.

$$\frac{\partial \underline{\epsilon}(z_t)}{\partial v_{t-1}} = \frac{\partial \overline{\epsilon}(z_t)}{\partial v_{t-1}} = 2b \frac{\partial z_t}{\partial v_{t-1}} < 0. \tag{8}$$

This means that, graphically, an increase in v_{t-1} shifts the interval $\overline{\epsilon}(z_t) - \underline{\epsilon}(z_t) = w_t - \rho_t$ from right to left relative to a fixed support of demand shock realizations of length 2Δ centered around zero. In the case of low demand uncertainty, i.e., when $\overline{\epsilon}(z_t) - \underline{\epsilon}(z_t) = w_t - \rho_t > 2\Delta$, an increase in v_{t-1} leads to a unique path from regime (12) to regime (2) to regime (23), with $z^*_{t,12} \geq z^*_{t,2} \geq z^*_{t,23}$ (see Figure 3).

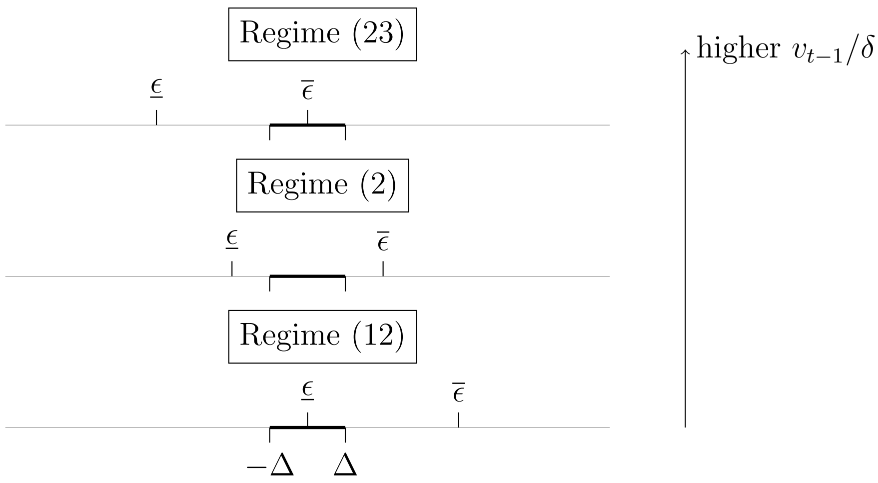

Figure 3: Trade cost path with low demand uncertainty

A low enough v_{t-1} implies that $\underline{\epsilon}(z_t) \in (-\Delta, \Delta)$ and $\overline{\epsilon}(z_t) > \Delta$ which leads to regime (12) and an optimal inventory level $z^*_{t,12}$. In this case, imports are so cheap that the firm seeks to reduce the probability of a stockout by holding imported goods in inventory in excess of expected sales. A stockout still occurs when demand turns out to be high, but the firm accumulates inventory when demand happens to be low. As v_{t-1} increases, we have $\underline{\epsilon}(z_t) < -\Delta$ and $\overline{\epsilon}(z_t) > \Delta$ so that we are in regime (2) and $z^*_{t,2}$ becomes the optimal inventory level. In this regime, the probability of a stockout is equal to one, i.e., the firm does not engage in stockout avoidance at all, but only ever sells exactly what it has in inventory. In other words, the firm prefers to stock out rather than to source domestically or to carry excess inventory into the subsequent period. As v_{t-1} rises still further, we obtain $\underline{\epsilon}(z_t) < -\Delta$ and $\overline{\epsilon}(z_t) \in (-\Delta, \Delta)$ which puts us in regime (23) where $z^*_{t,23}$ is the optimal inventory level. Imports are now so expensive that the firm never accumulates excess inventory but either stocks out, if demand is low, or turns to dual sourcing to cover high demand realizations.

Next, we can show that the optimal inventory levels in all three regimes decrease monotonically as v_{t-1} rises and that, at the values of v_{t-1} at which regime switches occur, the optimal inventory is continuous in v_{t-1}. Therefore, an increase in v_{t-1} and thus a temporary increase in the trade cost leads to a monotonic and continuous decrease in the optimal inventory. How an increase in the trade cost affects the optimal inventory z_t^* compared to expected sales $\hat{q}_t$ is illustrated by Figure 4.

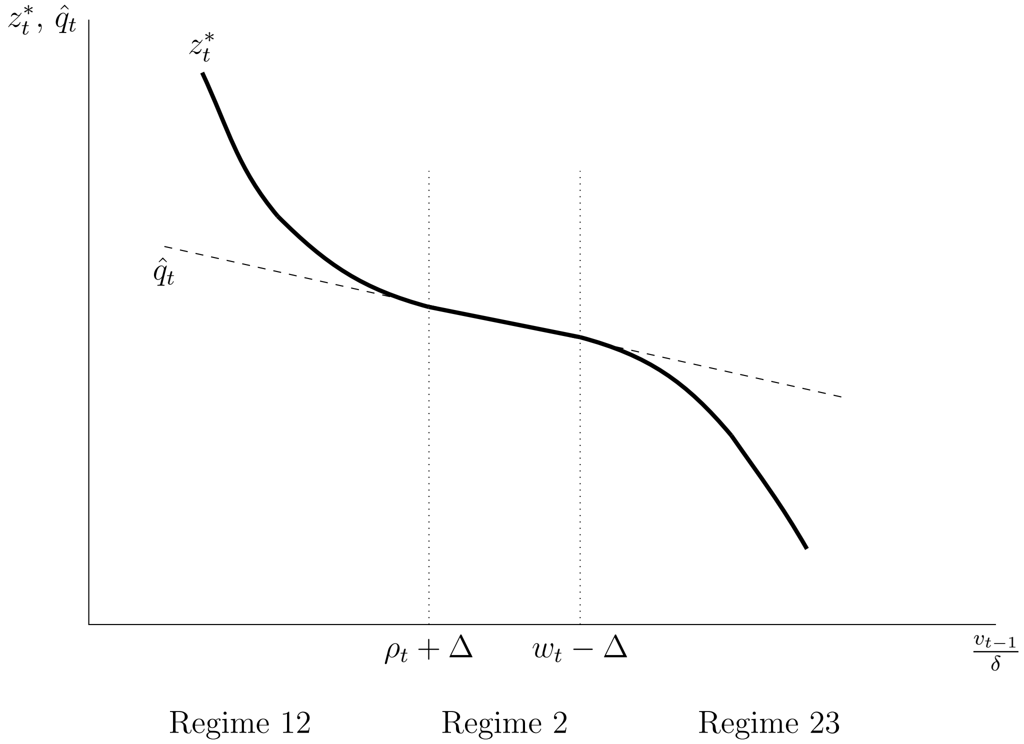

Figure 4: z_t^* and $\hat{q}_t$ – Low Demand Uncertainty

As we know from Lemma 2, $\hat{q}_t$ is linear in v_{t-1} with a slope of $-1/2b\delta$. In regime (2), $z_{t,2}^* = \hat{q}_t$ as no stockout avoidance takes place. Thus, as v_{t-1} rises, both $z_{t,2}^*$ and $\hat{q}_t$ decrease at the same rate. In the other two regimes, stockout avoidance implies that the optimal inventory reacts more strongly to a temporary trade cost change than expected sales. In other words, stockout avoidance magnifies the effect of a temporary change in the trade cost on the optimal inventory. The mechanisms driving this magnification effect can be easily seen in Figure 4. In regime (12), the firm seeks to reduce the probability of stocking out by holding inventory in excess of expected sales. An increase in v_{t-1} makes this stockout avoidance strategy more expensive and induces the firm to reduce its inventory relative to expected sales and thus more strongly than without stockout avoidance. This implies that, as the trade cost rises, the firm accepts a greater stockout probability, given by $(\Delta - \underline{\epsilon}(z_t))/2\Delta$, until we are in regime (2), in which the stockout probability is equal to one.

In regime (23), an increase in v_{t-1} also implies that the optimal inventory decreases faster than expected sales. But this comes from the fact that the firm now increasingly relies on domestic sourcing to avoid stockouts when demand turns out to be high. More precisely, as v_{t-1} rises, the likelihood of domestic sourcing, $(\Delta - \overline{\epsilon}(z_t))/2\Delta$, increases. We summarize the results as follows:

Proposition 1. *(i) A temporary increase in the trade cost reduces the optimal inventory z_t^*. (ii) Stockout avoidance magnifies the effect of a temporary trade cost increase, so that the optimal inventory z_t^* decreases by more than expected sales.*

Proof. See Appendix A.3. □

Proposition 1 implies that the effect of a trade cost increase on the optimal inventory is generally stronger when a firm engages in stockout avoidance than when it chooses not to do so. We now show that the same is true for the volume of imports. In regime (23), where the importer never accumulates excess inventory but instead seeks to avoid stockouts through dual sourcing, the import volume ordered in $t-1$ is given by $m_{t-1,23}^* = z_{t,23}^* < \hat{q}_t$. Moreover, we know from Proposition 1 that a temporary trade cost change within this regime affects optimal inventory, and thus the import volume, more than expected sales and hence more than without stockout avoidance.

In regime (12), where the importer potentially accumulates excess inventory, we have:

$$m_{t-1,12}^* = \begin{cases} z_{t,12}^* - z_{t-1,12}^0 & \text{if} \quad -\Delta < \epsilon_{t-1} \leq \underline{\epsilon}(z_{t-1}), \\ z_{t,12}^* & \text{if} \quad \underline{\epsilon}(z_{t-1}) < \epsilon_{t-1} < \Delta, \end{cases} \tag{9}$$

where

$$\begin{aligned} z_{t-1,12}^0 &= z_{t-1,12}^* - q_{t-1}^*(\epsilon_{t-1} \leq \underline{\epsilon}(z_{t-1})), \\ &= \frac{\Delta - \epsilon_{t-1} - 2\sqrt{\Delta\left(v_{t-2}/\delta - \rho_{t-1}\right)}}{2b}. \end{aligned} \tag{10}$$

An increase in v_{t-1} raises $z^0_{t-1,12}$ through its effect on ρ_{t-1}, i.e., by making excess inventory more valuable, and also lowers $z^*_{t-1,12}$. Hence, it must reduce imports, $m^*_{t-1,12}$, even more strongly than $z^*_{t,12}$. Moreover, since we know from Proposition 1 that the effect of a change in v_{t-1} on $z^*_{t,12}$ is greater than the effect on $\hat{q}_t$, it follows that a temporary trade cost change in regime (12) has a stronger effect on the import volume than on expected sales, and hence a stronger effect than in the absence of stockout avoidance. We may thus formulate the following proposition:

Proposition 2. *Stockout avoidance magnifies the effect of a temporary trade cost increase on the import volume, so that the import volume falls by more than expected sales.*

We can now easily verify that the magnification imparted by stockout avoidance is further strengthened by a mean-preserving increase in demand uncertainty (i.e. an increase in Δ). This effect occurs both in regime (12) and in regime (23). By contrast, in regime (2), where there is no stockout avoidance, the impact of a temporary trade cost change on optimal inventory and imports does not depend on Δ. We may therefore state:

Proposition 3. *A mean-preserving increase in demand uncertainty further strengthens the effect of a temporary trade cost change on the optimal inventory and the import volume when the firm engages in stockout avoidance.*

Proof. See Appendix A.4. □

A trade cost increase reduces inventory, and consequently imports, by more the greater is the level of demand uncertainty. There are two reasons for this. First, if imports are relatively cheap, greater demand uncertainty forces the firm to rely on a larger inventory of imported goods to hedge against stockouts. A temporary increase in the trade cost thus makes this stockout avoidance strategy more costly especially when demand uncertainty is high, forcing the firm to more strongly cut its inventory and imports. Second, when the firm seeks to avoid stockouts through dual sourcing, a temporary increase in the trade cost makes the firm more willing to switch to expensive domestic sourcing the higher is the degree of demand uncertainty.

4 Data and Descriptive Statistics

The empirical analysis requires us to distinguish between domestic and foreign purchases, preferably at the transaction level, and to have inventory at the detailed product level. This is what the data set first used by Hall and Rust (2000) and based on data from an anonymous US steel wholesaler offers.[10] Specifically, the data set collects detailed information on purchases, sales, and stocks of steel products between 1997 and 2006 for one steel wholesaler. Each product has a code identifying the group of products to which it belongs (e.g. PL075 for 3/4 inch thick plates) and a long description identifying more finely a product in that group according to its dimension and other characteristics (e.g., 96x240 PLATE 3/4 A-36). For each transaction (sales, purchases), we observe the date, unit price, total weight, number of units (when relevant), and total value involved in the transaction. Purchase transactions have a code indicating whether they are domestic, foreign or of unknown origin. Note, however, that a significant fraction of the transactions is without a known origin, and that the exact foreign source is not known.[11]

Because some sub-periods have missing observations, the sample period we consider for inventory is between January 2001 and February 2004. Our sample therefore includes a period of about one year preceding the Bush safeguard steel tariffs, the entire period during which the Bush tariffs were in place (March 20, 2002 - December 4, 2003), and a few months after the Bush tariffs. Based on the raw inventory data, this period has a total of 567 distinct product codes and 1,794 distinct products at the long description level over eight specific dates of inventory measurements (one in 2001; 3 in 2002; 2 in 2003; and 2 in 2004).[12] Not all products have a reported inventory for each of these dates; the inventory measure ranges between one and eight observations per product. The inventory measure is reported in pounds (and number of units when relevant). It represents the 'on

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[10]We thank George Hall for making the data available to us.

[11]According to Hall and Rust (2000), imports are ordered up to 12 weeks in advance while some domestic purchases are made with a one or two day notice. Most sales orders are filled within 24 hours of commitment, 95 percent of sales orders are filled within 5 days. Back-orders occur only occasionally. Customers expect the firm to have products on hand. Also note that the firm is able to price discriminate across customers, so it appears to have some market power with respect to customers, as assumed in our model.

[12]The number of products is smaller than in the sales and purchases data, the latter having many products with just one transaction. This could be due to misspelling and coding errors. We consider the stock data as being representative of the product dimension of the data.

hand' inventory and thus what is in the warehouse for a given product at each of these specific dates.[13] Depending on the date, the reported inventory involves between 689 and 933 products at the long-description level. In the econometric analysis, we use 6,348 observations corresponding to a total of 1,772 products after eliminating a few unusual codes and long descriptions.

An important component of the econometric analysis is the use of the Section-201 tariffs on steel products introduced in 2002. The details can be found in President Bush's Proclamation 7529 published on March 5, 2002 ('To Facilitate Positive Adjustment to Competition From Imports of Certain Steel Products'). A total of 172 8-digit HTS steel products were subject to the new tariff, effective on March 20, 2002: 129 steel products received a 30% tariff, 33 received a 15% tariff, 7 received a 13% tariff, and 3 received an 8% tariff.[14] Although designed to be in place for three years, with gradually lower tariff rates after each 12-month period, the tariffs were suddenly cancelled with an effective date of December 5, 2003, shortly after the US lost the case at the WTO. We should point out that, in addition to country exclusions included in the Proclamation (countries benefiting from a preferential trade agreement with the US such as Canada and Mexico, and developing countries, collectively representing less than 9% of the US steel import market), several rounds of exclusion took place during the first year of these tariffs. These are firm- and product-specific exclusions regarding very specialized products that were in too short supply in the United States. These exclusions were not extended to other firms in the United States, let alone to other countries (Bown, 2013). The products sold by the wholesaler are standard steel products and very unlikely to be subject to these firm-specific exclusions. Also notice that a number of antidumping and countervailing orders affecting the US steel industry were in place during the same period. But we could not ascertain any direct effects of these measures on the steel wholesaler.

The structure of the Bush tariffs is sufficiently concentrated so that we can construct a crosswalk between the product description of the wholesaler and the 8-digit HTS product code in the tariff proclamation. We proceed as follows. First, we match each long-description product in the wholesaler data with a four-digit HTS code (version 2002). Sec-

[13] At specific instances explained below, we use additional information contained in the stock data at these specific dates, including the weight (and number of units) already sold (or 'reserved') but not yet shipped out of the warehouse, and the weight (and number of units) that have been ordered but not yet received in the warehouse.

[14] See also Bown (2013), Hufbauer and Goodrich (2003), and Read (2005).

ond, we define a product as having a “high” tariff (H) when the product can be assigned a four-digit HTS code for which all 8-digit subcategories are subject to a 30% initial tariff rate. Examples of this are most flat-rolled products comprising standard plates, sheets and coils (HTS 7208, 7209, 7210, 7211, 7212). Similarly, we define a product as having a “low” initial tariff (L) when a product can be assigned a 4-digit HTS code for which all 8-digit subcategories are either not subject to a Section-201 tariff or are subject to it but at a lower initial tariff rate of 13 or 15% instead of the initial 30% rate. Examples of this are most pipes and tubes, including fittings (HTS 7305, 7306, 7309). We assign four more codes. A code 0 is assigned when a product clearly belongs to an HTS category without Bush tariff, which is the case for most stainless steel products (such as flat-rolled products included in HTS 7219 and 7220). The code HU is chosen when a product can be assigned a 4-digit HTS code for which some 8-digit subcategories are subject to the “high” initial tariff while others are not, thus creating uncertainty whether this product is subject to the high tariff or not. These are typically products with a description suggesting a more specialized product such as flat-rolled products with alloy other than stainless (HTS 7225 and 7226), or angles, shapes and sections (HTS 7216). Similarly, we put products in an LU category when there is similar uncertainty regarding whether a product is subject to a “low” initial tariff. We assign a code NA when the description of the product does not allow us to classify it. This exercise results in having 1,447 products at the long-description level with an H tariff level, and 97 products with an L tariff level. The remaining 228 products are assigned codes of 0, LU, HU, or NA. The large share of products with a high tariff is not surprising as the wholesaler deals mainly in standard steel plates and sheets all with distinct long descriptions based on thickness, width and length.

Table 1 summarizes a few characteristics of the purchase transactions by considering the subset of products with at least five transactions during the 2001-04 sample period. The average share of foreign purchase transactions is 33% with an average size which is about four times the average size of domestic transactions. Domestic purchases of a product command a price premium of 6.7% on average over foreign purchases of the same product. This is consistent with the fact that domestic products may be more immediately available than their imported counterparts. This immediacy can also be evaluated by computing the average number of days in between transactions with the same origin. At the product level, domestic transactions are indeed a lot more frequent than foreign ones since there is an average of 76 days in between domestic purchases and 107.2 days in between foreign purchases. If these summary statistics are interesting, one should not read too much into them, especially as the standard deviations are generally high. We now turn to the econometric analysis to test several hypotheses emerging from the model.

	$\frac{\#Foreign}{\#Identified}$	Dom. Price Premium	Purch. Weight Domestic	Purch. Weight Foreign	Days Domestic	Days Foreign
Average	0.331	0.067	45,889	183,549	76.03	107.20
S.D.	0.232	0.115	37,190	138,588	52.48	57.54

Table 1: Purchase Characteristics across Products and Periods

5 Empirical Analysis

In this section, we focus on testing results from Propositions 1-3. In particular, we want to check whether the mechanisms through which stockout avoidance affects inventory and imports, notably a change in the stockout probability and a change in the domestic sourcing ratio, can be observed in the data. We start by considering how the firm adjusts its inventory-sales ratio in response to a rise in the import tariff, and check for the presence of the two mechanisms. We then investigate the effect on the import-sales ratio, and finally consider how demand uncertainty affects the impact of the tariff.[15]

5.1 The Effect of a Tariff on Inventory and Imports

According to Proposition 1, a temporary tariff leads to a greater reduction in inventory than in sales. Notice that the relative decrease in inventory relative to sales holds for all products with a positive probability of being imported except in regime (2) where the

[15]We consider the observed tariff changes to be largely unanticipated. In particular, the announcement period prior to imposition of steel tariffs was too short—only two weeks from March 5 to 20, 2002—to have any effect on inventory; and the premature removal of the tariff on December 5, 2003 probably came as a surprise to the firm, given that the tariff was initially announced to last for three years. The reduction in the tariff rate following the first year of the tariff was anticipated, as it was announced when the tariff was initially introduced. While it would be difficult to separate any anticipation effects in year one of the tariff from the direct effect of the tariff, below we nevertheless consider effects separately for period 1 of the tariff (March 20, 2002 to March 19, 2003) and period 2 (March 20, 2003 - December 4, 2003).

decrease in inventory is the same as the decrease in sales. However, whether prior to the imposition of the tariff products are only imported (as in regime (12)) and thus have an initial import share (MS) equal to one, or not (as in regime (23)) because they exhibit dual sourcing, we expect the inventory-sales ratio to fall after the imposition of a tariff. But it is also the case that products may switch to new regimes after the imposition of the tariff, as the firm either accepts a greater probability of stockouts or shifts toward domestic sourcing. Such a switch always contributes to decreasing the inventory-sales ratio even when regime (2) is involved.[16] We start by testing the following hypothesis:

Hypothesis 1 *Consider products with a positive initial import share. Products subject to the tariff experience a decline in their inventory-sales ratio relative to products unaffected by the tariff.*

We test this hypothesis using a difference-in-difference (DiD) approach that compares the change in the inventory-sales ratio (tariff-period inventory-sales ratio minus pre-tariff-period inventory-sales ratio) across products with

$$YS_{it} = \phi_i + \lambda_t + \gamma T_{it} + u_{it}, \tag{11}$$

where the dependent variable, YS_{it}, is the inventory-sales ratio measured as the total weight of product i in the warehouse divided by its sales (total weight), both at date t, ϕ_i is a product fixed effect, and λ_t is a time-period fixed effect. T_{it} captures the tariff level for product i at time t, where $T_{it} = 1$ if product i is subject to a high tariff and the inventory date t is within the tariff period, and $T_{it} = 0$ otherwise. Thus, $T_{it} = 0$ is also assigned to all products with a low tariff irrespective of the date. Hypothesis 1 requires $\gamma < 0$.

Obviously, inventory measures and sales do not necessarily have the same date. Thus, inventory measured at date t is divided by the sales (including internal sales) corresponding to the pre-tariff period when date t is between January 1, 2001 and March 19, 2002 and by the sales corresponding to the tariff period when date t is between March 20, 2002 to March 1, 2004. For each product, we therefore have up to eight measures of the inventory-sales ratio, YS_{it}.

Table 2 presents the results where, for each specification, the top row is the estimate

[16]These observations are also valid for the case with high demand uncertainty; see Appendix A.5.

	Base	2001-2003	# Sales $\geq$ 5	Bal.	HU=H	Available
γ	-0.100***	-0.060*	-0.075**	-0.093***	-0.104***	-0.079**
	(0.025)	(0.029)	(0.023)	(0.025)	(0.026)	(0.024)
N	2706	2152	2425	1232	2890	2690
R^2	0.505	0.535	0.464	0.429	0.482	0.511

Table 2: Hypothesis 1 - Results. ***: $p < 0.001$; **: $p < 0.01$; *: $p < 0.05$.

and the second row is the standard error. All results are significant at the 5% level or lower.

Column "Base" presents our baseline findings. In this specification, we use the two periods as just defined. Note that the second period includes inventory measures just after the end of the tariff. We include all products regardless of whether they are observed to have dual sourcing but we place two restrictions on the sample. The first is to consider products with at least three sales during each period. We do this to ensure that the products under consideration are actively traded. The second restriction is that, in order to deal with outliers and in particular with a small number of products with very large inventories (and thus inventory-sales ratios), we use Tukey's fence, i.e., we remove observations that are more than the standard practice of 1.5 times the interquartile range beyond the first and third quartile. In the present case, this mainly removes products with the largest ratios but also a few with very small ones. We also omit products with tariff classifications other than H or L.

Our findings are in line with Hypothesis 1: there is a negative and statistically significant effect on the inventory-sales ratio of the high tariff relative to the low one. The impact is large since $\gamma = -0.1$ represents 65% of the mean ratio of the sample (0.154) (with a standard deviation of 0.147).

Several sensitivity checks corroborate our main findings. In column "2001-2003", we estimate the parameter γ using only data for the period 2001-2003. This corresponds to ignoring inventory measurements just after the end of the tariff period. In column "# Sales $\geq$ 5", we consider all the products with at least five (instead of three) sales in each period. The sign is still negative and significant but at a higher level. In column "Bal.", we use only products that are observed at each date of inventory measurement. This forces the set of products to be the same at each inventory measurement date and thus reduces considerably the number of observations (for a total of 199 products with H and L tariff classifications). The impact of the high tariff relative to the low one is still large since $\gamma = -0.093$ represents 47% of the sample mean of YS_{it} (mean: 0.196; standard deviation: 0.373). In column "HU=H", we include the products with a "probably high" tariff classification in the H category. In column "Available", we use an alternative measure of inventory, one that excludes the weights of products that have already been sold but not yet shipped out of the warehouse. Results are very similar to the base case in these two last instances.

5.2 The effect of a tariff on the stockout probability

We now check the first mechanism through which the inventory-sales ratio changes with a change in tariff, namely through a change in the stockout probability. We start by presenting evidence that stockouts are indeed a relevant feature of the data. There is considerable evidence of products with zero inventory in the data over the dates for which we have inventory levels. In fact, out of 1,772 products, 421 of them (23.7%) have at least one zero inventory measure. Not all zero measures, however, should be considered as deliberate stockouts and thus arising from a decision not to import or to buy domestically. For instance, there are new products that have been ordered but not yet received. There are also products that the wholesaler only purchases when a customer orders them and thus show up as zero inventory for a majority of dates. To study "deliberate" stockouts, we therefore select products based on two criteria. First, we consider a product as relevant for our purposes if it has at least three positive inventory measures. This ensures that the products under consideration pass a minimum threshold in terms of effective inventory presence. Second, a product has relevant stockout episodes when it has no more than two zero inventory measures. This eliminates all the products for which stockout episodes dominate over the relevant period. We further restrict the data set to six dates (2001-03) corresponding either to before or during the tariff period.

The total number of relevant products and the share of products with stockouts is presented in Table 3. Because we want to consider the link between stockouts and the initial import share, we first consider only the products for which an import share can be computed during the period prior to the implementation of the tariff (Col. (a)). In this column there are 283 products, and the stockout rate is 28.3%. In other words, 28.3% of the 283 products have a stockout episode. To put this in perspective, consider Col. (b), which includes all the products involved during the period whether or not import shares can be computed (but still subject to having at least three positive inventory measures). The total

	With Import Share	All	Bal	Available
	(a)	(b)	(c)	(d)
Stockout Rate	28.3%	15.2%	28.2%	12.3%
Total # Products	283	735	280	283

Table 3: Stockout Rates

number of products is now more than twice as high, namely 735, but the stockout rate is nearly half (15.2%). This indicates that, in relative terms, stockout episodes are mainly associated with products that are actively traded during the pre-tariff period, a feature consistent with the model. Col. (c) considers a balanced set of products before and during the tariff period; that is, the same set of products before and during the tariff period. This constraint also selects the products that are active in terms of purchases and/or sales. Indeed, the total number of products is relatively low (280) but the stockout rate is high and, with 28.2%, nearly identical to that in Col. (a). Col. (d) considers an alternative measure of inventory, one based on the 'availability' of the products. According to this measure, inventory does not include what the wholesaler has sold but not yet shipped to customers, but it includes what the wholesaler has 'ordered' but not yet received. This measure of inventory is useful because it prevents us from counting as a stockout an episode in which there is no inventory in the warehouse but an order is on its way. In addition, it includes as stockout, products that effectively have no inventory because they have already been sold but not yet shipped to buyers. With this definition of inventory, the stockout rate is still 12.3% out of 283 products.

If the evidence suggests significant stockout rates irrespective of the criteria, we still need to link these episodes to import shares. According to the model, products that have a high import share are more likely to experience a stockout when hit by a tariff, whereas products with a small initial import share are predicted to experience no change or even a decrease in the stockout probability, as the firm switches to domestic sourcing to avoid stockouts. The treatment effect may hence be non-monotonic depending on the product's initial import share. Thus we may state:

Hypothesis 2 *Consider products with a positive initial import share. The imposition of a tariff raises the stockout probability of products with an initial import share sufficiently close to one, but lowers the stockout probability of products with a low initial import share.*

Tariff	Pre/post	Baseline	Stockout 2	Stockout 3	Cutoff 0.7
Low	pre	0.0556	0	0.111	0.0556
		(0.162)	(0.000)	(0.323)	(0.162)
Low	post	0.0556	0.0278	0.167	0.0556
		(0.137)	(0.118)	(0.383)	(0.137)
High	pre	0.0604	0.044	0.110	0.0637
		(0.180)	(0.177)	(0.314)	(0.195)
High	post	0.0879	0.0696	0.209	0.0858
		(0.192)	(0.205)	(0.409)	(0.185)

Table 4: Stockout for products with sufficiently high import share, by tariff and period.

We investigate only the first part of Hypothesis 2 simply because the data do not allow us to set up a control group for products with low import shares. Hence, for each product with an initial import share of at least 0.9, we compute the stockout fraction, defined as the number of stockout episodes relative to the total number of inventory observations for this product during the relevant period.[17] We then compute the average of this measure separately for high-tariff products and for low-tariff products, both before and after the imposition of the tariff. Table 4 presents the results.

For example, for the baseline results (col. Baseline), the average number of stockout episodes per product increases for high-tariff products from 6% before the tariff to an average of 8.8% per product during the tariff period. By contrast, the average stockout fraction for low-tariff products remains unchanged at 5.5% per product. This is in line with Hypothesis 2. We repeat this analysis in three different ways. In column Stockout 2, we use the stockout fraction for each product based on the alternative measure of inventory that we called 'Available' in the previous table. In column Stockout 3, instead of using stockout fractions, we use a stockout indicator per product and period (equal to 1 if there is a stockout during a period and 0 otherwise). In column Cutoff 0.7, we expand the set of products to those with an initial import share of at least 0.7. Across all these sensitivity checks, the findings are qualitatively similar: For products with a high import share, the increase in the stockout fraction is higher for the high tariff products compared to low-tariff products. This is in line with Hypothesis 2, but the means are imprecisely estimated and the results are not statistically significant.

[17]Note that the stockout fraction is different from the stockout rate, which was defined above as the share of products with a stockout episode.

One of the reasons is that the raw inventory data for the relevant period are provided for at most six dates for each product. To get around this limitation, we use the raw inventory, sales, and purchase data to reconstruct daily inventory.[18] Reconstructing inventory is complex and only possible for a subset of products especially when we also need to compute the pre-tariff import share.

After aggregating the daily inventory to the monthly level, we perform a difference-in-difference analysis based on the following regression equation:

$$Y_{is} = \phi_i + \lambda_m + \gamma T_{it} + u_{is}, \tag{12}$$

where $Y_{is} \in [0, 1]$ is the fraction of days that product i experiences a stockout in month-year s, ϕ_i is a product fixed effect, λ_m is a month fixed effect, and T_{it} equals 1 for high-tariff products in the period during the Bush tariff, and 0 otherwise. Thus γ is the parameter of interest. The results are reported in Table 5.

Our baseline specification uses monthly data for January 2001-December 2003 on 133 products (col. a) for which the import share is at least 0.9. Since the parameter γ has a difference-in-difference interpretation, we find that the effect of the tariff increases the average number of stockout episodes by 5.7% for high-tariff products as compared to low-tariff products. Thus, among the set of products with an import share of at least 0.9, the high-tariff products experience a higher average number of stockout episodes during the Bush tariff than the low-tariff products. This effect is statistically significant at conventional levels. Interestingly, it is also larger than the corresponding effect that can be computed from the means of Table 4. In that case, the differential impact of the Bush tariff on high-tariff products as compared to low tariff products is equal to 2.75%

[18] In order to generate a daily measure of inventory for each product at the long description level, we compute for each product $Inv_t = Inv_{t-1} + Purchases_{t-1} - Sales_{t-1} - Adj_{t-1}$, where Inv_t is the inventory by weight at date t (at the 'start of the day'), and $Purchases_{t-1}$, $Sales_{t-1}$ and Adj_{t-1} are respectively purchases, sales, and adjustments (sales coming from transformations such as cutting off a sheet from a coil) at date $t-1$ by weight. We use directly reported inventory observations in two ways. First, the reported inventory data allow us to anchor the computed inventory measure (for instance on February 10, 2000 for which we have reported inventory observations in the data). Second, we use them to check how Inv_t matches with reported inventory at up to 6 dates within our 2001-03 sample period. For most products we obtain an exact match between our computed daily inventory and the reported inventory at these dates. When the match is not exact, we are generally missing only a few units. These cases typically arise for the most frequently sold products. The discrepancies may come from mis-labelled sales transactions.

	(a)	(b)	(c)	(d)
$\widehat{\gamma}$	0.057*	0.070*	0.053	0.034
	(0.025)	(0.024)	(0.091)	(0.024)
products	133	133	133	145
time periods	36	39	2	36
R^2	0.405	0.415	0.044	0.388

Table 5: Stockout difference-in-differences (*: $p < 0.05$).

when using the baseline means (since $(8.79 - 6.04) - (5.56 - 5.56) = 2.75$). The larger effect based on Eq. (12) could be due to our use of a slightly different set of products, to the inventory reconstruction, or to the more precise estimate of the stockout fraction.

We also report the results for a number of sensitivity analyses. In column (b), we report the results for the period January 2001-March 2004. In column (c), we aggregate the results to two periods (pre-tariff and tariff). In this specification, λ_m is replaced by a period fixed effect. In column (d), we report the results for the less strict definition of "high import share" of at least 0.7, and use all 145 products for which a pre-tariff import share can be computed.

Effect estimates from the sensitivity analyses are qualitatively similar. However, in column (c), where three years of data are aggregated into two data points, and in column (d) the estimated effects are positive but not statistically significant.

The evidence on how the tariff affects the stockout probability suggests that it increases for products with high import shares that are subject to the high tariff. This effect contributes to reduce foreign sourcing. We now check if the firm adjusts its dual sourcing strategy by turning toward more domestic sourcing.

5.3 The effect of a tariff on the firm's dual sourcing strategy

The second mechanism through which the firm adjusts its inventory-sales ratio following the imposition of a tariff is through a change in its dual sourcing strategy. In particular, the model predicts that the firm will reduce foreign relative to domestic sourcing and thus experience a decline in its import share. We may hence test the following hypothesis:

Hypothesis 3 *Consider products with an initial import share strictly between zero and one. The imposition of a tariff leads to a reduction in the import share.*

We construct the import share MS_{it} variable as the share of total weight of product i bought abroad during period t to the total weight bought domestically and abroad. In particular, the variable MS_{i0} refers to the import share in the pre-tariff period (January 3, 2000 - March 19, 2002), and MS_{i1} refers to the import share for the time period during which the tariff was in effect (from March 20, 2002). There are 280 products for which an import share can be computed for both periods. Because the steel tariff is lower during the second year than during the first year, we also compute the import share for the first year of the steel tariff (March 20, 2002 to March 19, 2003). There are then 246 products with positive import shares both in the pre-tariff period and in year one of the tariff. Obviously, having only one or two measurements of the outcome variable during the tariff period complicates the identification of effects. The analysis for this hypothesis therefore deviates from that in the previous subsections.

In particular, because the variable of interest is a share, we use a fractional regression model (see Papke and Wooldridge, 1996). Our specification is

$$MS_{it} = \Lambda\left(\beta_0 + \beta_1 T_{it} + u_{it}\right), \tag{13}$$

where $\Lambda(\cdot)$ is the cumulative distribution function of a standard logistic random variable. Hypothesis 3 requires that the parameter of interest, β_1, be negative.[19]

Table 6 presents the results. In our main specification we reject the null hypothesis that $\beta_1 \geq 0$. This is evidence in favour of Hypothesis 3, since a negative value of β_1 corresponds to a decrease in the import share from the pre-tariff period to the tariff period. Importantly, our conclusion is unchanged when we restrict our attention to products with strict dual sourcing (col. b).

Going beyond a literal reading of the hypothesis, we also document how the change in the import share varies with the level of the initial import share. To do so, we estimate

$$MS_{i1} - MS_{i0} = \beta_0 + \beta_2 MS_{i0} + u_i \tag{14}$$

using linear methods. The result (ΔMS in col. c) indicates that a higher initial import share leads to a stronger decrease in the import share, as we reject the null hypothesis that $\beta_2 \geq 0$. The magnitude of this effect is significant since it indicates that products

[19] It can be estimated using standard methods, for example using **glm** in R's **stats** package.

	Base	MS $\in (0,1)$	ΔMS	Base	MS $\in (0,1)$	ΔMS
	(a)	(b)	(c)	(d)	(e)	(f)
β_0	-0.061	0.406**	0.138***	0.013	0.491***	0.115**
	(0.101)	(0.127)	(0.034)	(0.112)	(0.137)	(0.039)
β_1	-0.413 **	-0.531 **		-0.358*	-0.387*	
	(0.145)	(0.178)		(0.160)	(0.192)	
β_2			-0.493 ***			-0.404***
			(0.053)			(0.059)
N	590	280	295	490	246	245

Table 6: Hypothesis 3 - Results. ***: $p < 0.001$; **: $p < 0.01$; *: $p < 0.05$.

with an initial import share near one see their import share decrease by more than 40% with respect to those with an import share near zero.

The results hold when considering only the first year of the steel tariff (Col. d, e, f) instead of the entire tariff period, although with a weaker level of significance in Col. (d) and (e) because of the smaller number of products taken into account.

5.4 The Effect of a Tariff on Imports

What is the effect of the tariff on the import-sales ratio? Proposition 2 indicates that we should also expect this ratio to fall. We thus test:

Hypothesis 4 *Consider products with a positive initial import share. Products subject to the tariff experience a decline in their import-sales ratio relative to products unaffected by the tariff.*

We test this hypothesis in the same way as Hypothesis 1 by simply re-interpreting YS_{it} in Eq. (11) as product i's import-sales ratio. Now, t should be interpreted as one of two periods: the pre-tariff period (Jan. 1, 2001- March 19, 2002) and the tariff period (March 20 , 2002 - March 1, 2004). We therefore have two measures of the import-sales ratio, one prior to the implementation of the tariff and one during the tariff period. The other variables and parameters have the same interpretation. Hypothesis 4 requires $\gamma < 0$.

Like for Hypothesis 1, we impose the condition that products should have at least three sales in each period and we omit products with classifications other than H and L. Although there is no other restriction, the total number of products involved is small

	Base	2001-2003	HU=H	# Sales $\geq$ 5	# Sales $\geq$ 10
γ	-0.273*	-0.217	-0.278**	0.249*	-0.283*
	(0.105)	(0.111)	(0.105)	(0.110)	(0.116)
N	218	212	226	198	172
R^2	0.760	0.757	0.755	0.764	0.753

Table 7: Hypothesis 4 - Results. ***: $p < 0.001$; **: $p < 0.01$; *: $p < 0.05$.

(about 100 products). This is because imposing a minimum number of sales in each period restricts the number of products with foreign sourcing.

Table 7 presents the results. Our findings are in line with Hypothesis 4: there is a negative and statistically significant effect on the import-sales ratio of the high tariff relative to the low one. The impact is large but relatively smaller than in the case of the inventory-sales ratio. This is the case since $\gamma = -0.273$ represents 51% of the mean import-sales ratio (mean: 0.533; standard deviation: 0.373). However, notice that we may be underestimating this effect since, by restricting our sample to products with a minimum number of sales during both the pre-tariff and tariff periods, we may be eliminating products that have no imports during the tariff period.

Table 7 also presents a few sensitivity checks that are consistent with our main findings. In column "2001-2003", the parameter γ is estimated by using only data for the period 2001-2003. The estimate is not significant at the 5% level but, although lower, still has a negative sign. Including products with HU in the sample (col. "HU=H") improves the level of significance without changing much the estimate. In column "# Sales $\geq$ 5", we consider all the products with at least five (instead of three) sales in each period. The sign is still negative and significant at the 5% level. In column "# Sales $\geq$ 10", we restrict the products to a minimum of 10 sales per period. The results are very similar to the benchmark case despite a smaller number of products (86).

5.5 The effect of demand uncertainty on the effectiveness of protection

Our model predicts that an increase in demand uncertainty magnifies the effect of the tariff (Proposition 3). This can be examined empirically by checking whether products exhibiting different degrees of demand uncertainty, ceteris paribus, exhibit different declines in inventory after the tariff is imposed. Specifically, we may state:

Hypothesis 5 *The imposition of a tariff leads to a larger decrease in inventory the greater is the product's level of demand uncertainty.*

We construct a measure of demand uncertainty for each product based on an extended sample period (2000–2004) where we aggregate the data to a time series of monthly sales for each product. We then compute the standard deviation of sales for each product i. This is our measure of demand uncertainty, which we call D_i. We use the same regression equation as for Hypothesis 1 except that the dependent variable is now the level of inventory and not the inventory-sales ratio, and we add an interaction effect of D_i with the tariff effect term. In other words, our regression equation for Hypothesis 5 is:

$$Y_{it} = \phi_i + \lambda_t + \gamma T_{it} + \delta T_{it} D_i + u_{it}, \tag{15}$$

where Y_{it} is inventory (in pounds) of product i at date t, δ measures the response of the tariff effect to demand uncertainty, and all other terms are as in (11). In particular, like for Hypothesis 1, date t corresponds to the inventory measurement dates.

We first estimate this model using the equivalent baseline specification for Hypothesis 1 (i.e., using a difference-in-difference approach and Tukey's fence to eliminate outliers), but including the regressor $T_{it}D_i$. The results are presented in Table 8-(a). We find that higher levels of demand uncertainty strengthen the negative effect of the tariff we found earlier (Hypothesis 1).[20] Given a mean value of D_i equal to 3.5, the effect of demand uncertainty is modest, but significant, as compared to the overall tariff effect. To rule out that the level of demand is driving the effect, we estimate the same specification after dividing inventory and the demand uncertainty measure by the mean of sales (Col. b). The estimated effect has the same sign, and is statistically significant again. We carry out the same estimations (Col. c and d) for the balanced sample of products. Higher levels of demand uncertainty also strengthen the negative effect on inventory although with a weaker level of significance in Col. (d).

Thus, demand uncertainty strengthens the protective effect of the tariff in the sense that products featuring greater demand uncertainty show a greater decline in inventory

[20]The high tariff has a significant impact on the level of inventory like it had in Table 2: inventory decreases by 12,189 pounds. Given a mean sample value of 17,936 pounds (and an interquartile range of 22,932 pounds), the fall in inventory is equal to 67.9%. The implication for the inventory-sales ratio is that the impact of the tariff is predominantly through changes in inventory, not sales.

	(a)	(b)	(c)	(d)
γ	-12.189***	5.596	-16.444**	0.502
	(3.217)	(7.096)	(4.992)	(5.045)
δ	-0.552***	-3.417***	-0.867***	-1.332*
	(0.142)	(0.726)	(0.242)	(0.598)
N	3813	3813	946	946
R^2	0.646	0.760	0.563	0.897

Table 8: Hypothesis 5 - Results

when hit by the tariff.

All in all, using the Bush steel tariffs for identification, we find considerable empirical evidence to support the predictions of our theoretical model. In particular, we find that a trade policy shock has statistically significant and economically sizeable effects on inventory investment and on imports relative to sales, and that the two mechanisms at the root of the firm's adjustments can be captured empirically.

6 Conclusions

Demand uncertainty matters especially for international trade, as manufacturers, retailers and wholesalers need to commit to sourcing well before the time products are purchased by final users. The financial crisis of 2008 created significant and widespread demand uncertainty, in particular when the demand for intermediate products suddenly dropped leading to a trade collapse (Baldwin and Freeman, 2021). Of course, the global supply chain disruptions associated with COVID-19 are also manifestations of the impacts of widespread and large unexpected shifts in demand. These are just two examples, both involving worldwide demand uncertainty. As such they are only the tip of the iceberg.

But it is also the case that international trade costs rose significantly during COVID-19. Airfreight rates between Hong Kong and North America for instance rose from \$3.62 per kilogram in December 2019 to \$12.72 in December 2021 (https://www.statista.com/statistics/1106691/air-freight-rates-globally-coronavirus-impact/) and global container sea shipping rates were four times higher at their peak in September 2021 as compared to August 2020. As mentioned in the introduction, trade policies also became more active during this period. Even if they are not permanent, several of these changes took place over a sufficiently long period of time to alter sourcing and inventory decisions. A McKinsey survey of global supply chain leaders suggests that, as a result COVID-19, 61% of companies have increased inventory of critical products and 55% had taken action to diversify their sources of materials (Financial Times, 2021). But are these changes in inventory and sourcing due to increased demand uncertainty or to change in trade costs? And what are the economic mechanisms through which these firm decisions take place?

The present paper investigates these questions by explicitly introducing inventory decisions in a dynamic model of international trade with demand uncertainty, lead time between import orders and delivery, and barriers to trade, in which a firm prefers to import because products are cheaper abroad but with the option of also buying them domestically and having them quickly delivered at a higher price. Its effort to avoid stocking out allows us to investigate how importers adjust inventory and import volumes to changes in trade costs and what role demand uncertainty plays for this adjustment.

We identify three main effects that we also examine empirically through the response of an anonymous U.S. steel wholesaler to the imposition of Section-201 tariffs imposed by the Bush Administration on imports of steel products in 2002-03.

First, stockout avoidance amplifies the trade impact of protection. This is the case because the optimal inventory is generally more sensitive to a change in trade costs than expected sales. In effect, holding large inventory is worthwhile when trade costs are low and unattractive when they are high. Empirical results are consistent with this result since, using product-level data on imports, sales and inventories of different steel products, we find that both the inventory-sales and the import-sales ratios of products hit by a 30% tariff experience a large average decline compared to a control group of products subject to no or a lower tariff. In particular, the inventory-sales ratio decreases by up to 65% while the import-sales ratio decreases by 51% on average.

Second, higher trade costs imply more stockouts. This is at the heart of the issue and one of the mechanisms behind the first effect: higher trade costs make it more costly to hold inventory to respond to high realizations of demand, and thus firms accept a higher probability of stockout. The fact that higher trade costs also make domestic sourcing more attractive is not surprising. However, domestic purchases, by being more quickly available but also more expensive than imports, are still a source that firms prefer to avoid unless trade costs are sufficiently high. It is thus important to verify that stockouts play an empirical role. We find that they indeed do for this steel wholesaler.

Third, stockout avoidance implies that demand uncertainty magnifies the effect of trade costs. That is, the greater is demand uncertainty, the larger is the negative effect of trade costs, be it tariff or transportation cost, on the volume of inventory and hence on trade. Not surprisingly, greater demand uncertainty forces firms to put more emphasis on stockout avoidance, be this through greater inventory investment or greater reliance on costly domestic sourcing. This is also an effect supported by the empirical analysis.

Our analysis can be extended to other barriers to trade. Antidumping orders, in particular, have the potential of affecting the hedging strategy in a much stronger way than the safeguard tariffs studied in our empirical exercise. The reason is that antidumping orders are designed to eliminate the price difference between domestic and foreign sources (the 'dumping margin') and thereby to completely eliminate the attractiveness of the hedging strategy through inventory build-up. This means that, where stockout avoidance strategies matter due to uncertain demand, antidumping orders have the potential of having very strong protectionist effects.

Our paper has focused on how importers may hedge demand uncertainty. Another source of uncertainty is trade policy itself. Whether associated with Brexit or with the U.S. trade policy toward China, trade policy uncertainty is undoubtedly higher today than in the past. Anecdotal evidence suggest that trade policy uncertainty has significant inventory effects.[21] There are a number of studies showing that reducing trade policy uncertainty increases trade (Crowley et al., 2018, Feng et al., 2017, Handley and Limão, 2017, 2015), affects a firm's input mix and sourcing (see Handley et al., 2020), and that the ensuing trade flow dynamics are consistent with inventory adjustments (Alessandria et al., 2021). But, at the firm level, does trade policy uncertainty have the same impacts as demand uncertainty? The role of firms' stockout avoidance strategies, especially their inventory adjustment, has not yet been fully explored in this context. Making progress in this area also requires that more disaggregate inventory data become available.

[21]For instance, Hasbro, a U.S.-based toymaker which outsources a large fraction of its production to Asia, not only has to deal with the demand uncertainty associated with its toys during the critical Christmas shopping season but also with trade policy uncertainty. Since it has essentially no domestic sources in the United States able to supply close substitutes, it has to rely on imports. This has consequences not only for the level of inventory it wants to hold but also for the timing of its orders (New York Times, Aug. 15, 2019, 'Trump delays a holiday tax, but toymakers are still worried').

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Appendix

A.1 Proof of Lemma 1

Whenever it exists, the optimal inventory is computed by finding z_t such that $\delta E[\text{MR}_t(\cdot)] = v_{t-1}$ (i.e., such that the discounted expected marginal revenue is equal to the marginal cost of an imported unit). Consider $z^*_{t,2}$ corresponding to the case where sales are always equal to inventory and thus where there is no excess inventory and no domestic sourcing. The discounted expected marginal revenue is:

$$\delta E\left[MR_t\right] = \delta \int_{-\Delta}^{\Delta} (a + \epsilon_t - 2bz_t)\frac{d\epsilon_t}{2\Delta}.$$

Setting it equal to the foreign unit cost, v_{t-1}, yields the optimal inventory:

$$z^*_{t,2} = \frac{a - v_{t-1}/\delta}{2b}. \tag{A.1}$$

This case requires $\underline{\epsilon}(z^*_{t,2}) < -\Delta$ and $\overline{\epsilon}(z^*_{t,2}) > \Delta$ which can be rewritten as:

$$\Delta < \text{Min}\left\{v_{t-1}/\delta - \rho_t, w_t - v_{t-1}/\delta\right\},$$

which in turn implies $2\Delta < w_t - \rho_t$. The optimal inventories $z^*_{t,123}$ and $z^*_{t,2}$ are mutually exclusive.

Inventory level $z^*_{t,12}$ corresponds to the case where the firm never sources domestically. The discounted expected marginal revenue is given by:

$$\delta E\left[MR_t\right] = \delta \left(\int_{-\Delta}^{\underline{\epsilon}(z_t)} \rho_t \frac{d\epsilon_t}{2\Delta} + \int_{\underline{\epsilon}(z_t)}^{\Delta} (a + \epsilon_t - 2bz_t)\frac{d\epsilon_t}{2\Delta}\right),$$

leading to the optimal inventory:

$$z^*_{t,12} = \frac{a + \Delta - \rho_t - 2\sqrt{\Delta\left(v_{t-1}/\delta - \rho_t\right)}}{2b}. \tag{A.2}$$

This case requires $\underline{\epsilon}(z^*_{t,12}) > -\Delta$ and $\overline{\epsilon}(z^*_{t,12}) > \Delta$ which can be rewritten as:

$$w_t - \rho_t > 2\sqrt{\Delta\left(v_{t-1}/\delta - \rho_t\right)}, \quad \Delta > v_{t-1}/\delta - \rho_t,$$

which in turn implies $w_t + \rho_t > 2v_{t-1}/\delta$.

Regime (23) corresponds to the case where the wholesaler never wants to accumulate excess inventory but could source domestically. The discounted expected marginal revenue is:

$$\delta E\left[MR_t\right] = \delta\left(\int_{-\Delta}^{\overline{\epsilon}(z_t)}(a+\epsilon_t-2bz_t)\frac{d\epsilon_t}{2\Delta}+\int_{\overline{\epsilon}(z_t)}^{\Delta}w_t\frac{d\epsilon_t}{2\Delta}\right),$$

leading to the optimal inventory:

$$z^*_{t,23} = \frac{a-w_t-\Delta+2\sqrt{\Delta(w_t-v_{t-1}/\delta)}}{2b}. \tag{A.3}$$

Since this case requires $\overline{\epsilon}(z_{t,23}) < \Delta$ and $\underline{\epsilon}(z_{t,23}) < -\Delta$, which, given $z^*_{t,23}$, can be written as:

$$\Delta > (w_t - v_{t-1}/\delta), \quad w_t-\rho_t > 2\sqrt{\Delta(w_t-v_{t-1}/\delta)},$$

which in turn implies that $w_t-\rho_t > 2(w_t-v_{t-1}/\delta)$.

Given our assumption that $w_t \geq v_{t-1}/\delta$, there is no interior solution for $z_{t,3}$, which corresponds to the case where the firm always engages in domestic sourcing ($\overline{\epsilon}(z_t) < -\Delta$). However, not surprisingly, if we allow $w_t < v_{t-1}/\delta$, then the firm never sources abroad so that $z^*_{t,3} = 0$. Regime (1) where sales would always be smaller than inventory ($\underline{\epsilon}(z_t) > \Delta$) so that the firm would want to accumulate excess inventory can be excluded since we assume $\rho_t < v_{t-1}/\delta$.

A.2 Proof of Lemma 2

- In regime (12), valid for $-\Delta < \underline{\epsilon}(z_t) < \Delta < \overline{\epsilon}(z_t)$, expected sales are:

$$\begin{aligned}\hat{q}_{t,12} &= \int_{-\Delta}^{\underline{\epsilon}(z_t)}\left(\frac{a-\rho_t+\epsilon_t}{2b}\right)\frac{d\epsilon_t}{2\Delta}+\int_{\underline{\epsilon}(z_t)}^{\Delta}z_t\frac{d\epsilon_t}{2\Delta} \\ &= \frac{-(a-\rho_t-\Delta)^2}{8b\Delta}+\frac{z_t}{2\Delta}(a+\Delta-\rho_t-bz_t).\end{aligned}$$

After substituting $z^*_{t,12}$ for z_t we obtain $\hat{q}_{t,12} = \frac{a-v_{t-1}/\delta}{2b}$. In addition,

$$\begin{aligned}z^*_{t,12}-\hat{q}_{t,12} &= \frac{\Delta+\frac{v_{t-1}}{\delta}-\rho_t-2\sqrt{\Delta\left(\frac{v_{t-1}}{\delta}-\rho_t\right)}}{2b} \\ &= \frac{1}{2b}\left(\sqrt{\Delta}-\sqrt{\frac{v_{t-1}}{\delta}-\rho_t}\right)^2 > 0.\end{aligned}$$

- In regime (2), where $\underline{\epsilon}(z_t) < -\Delta < \Delta < \overline{\epsilon}(z_t)$, the expected sales are given by

$$\hat{q}_{t,2} = \int_{-\Delta}^{\Delta} z^*_{t,2} d\epsilon_t / 2\Delta = z^*_{t,2} = \frac{a - v_{t-1}/\delta}{2b}.$$

- In regime (23), valid for $\underline{\epsilon}(z_t) < -\Delta < \overline{\epsilon}(z_t) < \Delta$, the expected sales are:

$$\begin{aligned}
\hat{q}_{t,23} &= \int_{-\Delta}^{\overline{\epsilon}(z_t)} z_t \frac{d\epsilon_t}{2\Delta} + \int_{\overline{\epsilon}(z_t)}^{\Delta} \left(\frac{a - w_t + \epsilon_t}{2b} \right) \frac{d\epsilon_t}{2\Delta} \\
&= \frac{(2bz_t - a)^2 + 4bz_t(w_t + \Delta) + (\Delta - w_t)(2a - w_t + \Delta)}{8b\Delta}
\end{aligned}$$

Substituting $z^*_{t,23}$ for z_t yields $\hat{q}_{t,23} = \frac{a - v_{t-1}/\delta}{2b}$. Moreover,

$$\begin{aligned}
z^*_{t,23} - \hat{q}_{t,23} &= -\frac{\Delta + w_t - \frac{v_{t-1}}{\delta} - 2\sqrt{\Delta \left(w_t - \frac{v_{t-1}}{\delta} \right)}}{2b} \\
&= -\frac{1}{2b} \left(\sqrt{\Delta} - \sqrt{w_t - \frac{v_{t-1}}{\delta}} \right)^2 < 0.
\end{aligned}$$

- In regime (123), where $-\Delta < \underline{\epsilon}(z_t) < \overline{\epsilon}(z_t) < \Delta$, the expected sales are equal to:

$$\begin{aligned}
\hat{q}_{t,123} &= \int_{-\Delta}^{\underline{\epsilon}(z_t)} \frac{a - \rho_t + \epsilon_t}{2b} \frac{d\epsilon}{2\Delta} + \int_{\underline{\epsilon}(z_t)}^{\overline{\epsilon}(z_t)} z_t \frac{d\epsilon_t}{2\Delta} + \int_{\overline{\epsilon}(z_t)}^{\Delta} \frac{a - w_t + \epsilon_t}{2b} \frac{d\epsilon_t}{2\Delta} \\
&= \frac{(2a - (\rho_t + w_t))(2\Delta - (w_t - \rho_t))}{8b\Delta} + \frac{z_t(w_t - \rho_t)}{2\Delta},
\end{aligned}$$

Substituting $z^*_{t,123}$ for z_t and simplifying we obtain $\hat{q}_{t,123} = \frac{a - v_{t-1}/\delta}{2b}$. Moreover,

$$\begin{aligned}
z^*_{t,123} - \hat{q}_{t,123} &= \frac{2a - (w_t + \rho_t)}{4b} + \frac{\Delta(w_t + \rho_t)}{2b(w_t - \rho_t)} - \frac{\Delta v_{t-1}/\delta}{b(w_t - \rho_t)} - \frac{1}{2} \frac{a\delta - v_{t-1}}{b\delta} \\
&= (2\Delta - w_t + \rho_t) \frac{\rho_t + w_t - 2\frac{v_{t-1}}{\delta}}{4b\,(w_t - \rho_t)},
\end{aligned}$$

where

$$z^*_{t,123} - \hat{q}_{t,123} \begin{cases} > 0 & \frac{v_{t-1}}{\delta} < \frac{\rho_t + w_t}{2} \\ = 0 & \frac{v_{t-1}}{\delta} = \frac{\rho_t + w_t}{2} \\ < 0 & \frac{v_{t-1}}{\delta} > \frac{\rho_t + w_t}{2} \end{cases}$$

A.3 Proof of Proposition 1

We first compute the foreign unit costs at which there are switches between regimes. The switch between regimes (12) and (2) occurs when $z^*_{t,12} = z^*_{t,2}$ and hence when $v_{t-1}/\delta = \rho_t + \Delta$. In a similar manner, we can compute the foreign unit costs at which the other regime switches occurs. The switch between regimes (2) and (23) happens $v_{t-1}/\delta = w_t - \Delta$.

Now consider a temporary tariff change characterized by $dv_{t-1} \neq 0$ and $d\rho_t = 0$. We find:

$$\frac{\partial z^*_{t,12}}{\partial v_{t-1}} = -\frac{\sqrt{\Delta}}{2b\delta\sqrt{v_{t-1}/\delta - \rho_t}} < 0, \tag{A.4}$$

$$\frac{\partial z^*_{t,2}}{\partial v_{t-1}} = -\frac{1}{2b\delta} < 0, \tag{A.5}$$

$$\frac{\partial z^*_{t,23}}{\partial v_{t-1}} = -\frac{\sqrt{\Delta}}{2b\delta\sqrt{w_t - v_{t-1}/\delta}} < 0. \tag{A.6}$$

Consider regime (12). Given that in this regime $\Delta > v_{t-1}/\delta$ and hence $\sqrt{\Delta} > \sqrt{\frac{v_{t-1}}{\delta} - \rho_t}$, we can establish that

$$\left|\frac{\partial z^*_{t,12}}{\partial v_{t-1}}\right| > \left|\frac{\partial \hat{q}_{t,12}}{\partial v_{t-1}}\right| = \frac{1}{2b\delta}.$$

In regime (2) we obtain:

$$\left|\frac{\partial z^*_{t,2}}{\partial v_{t-1}}\right| = \left|\frac{\partial \hat{q}_{t,2}}{\partial v_{t-1}}\right| = \frac{1}{2b\delta}.$$

In regime (23), where $\Delta > (w_t - v_{t-1}/\delta)$, we have:

$$\left|\frac{\partial z^*_{t,23}}{\partial v_{t-1}}\right| > \left|\frac{\partial \hat{q}_{t,23}}{\partial v_{t-1}}\right| = \frac{1}{2b\delta}.$$

A.4 Proof of Proposition 3

It follows directly from (A.4) and (A.6) that $\left|\frac{\partial^2 z^*_{t,23}}{\partial\Delta\partial v_{t-1}}\right| = \left|\frac{\partial^2 m^*_{t-1,23}}{\partial\Delta\partial v_{t-1}}\right| > 0$ and $\left|\frac{\partial^2 z^*_{t,12}}{\partial\Delta\partial v_{t-1}}\right| > 0$. Given that

$$m^*_{t-1,12} = \frac{a - \rho_t + \epsilon_{t-1}}{2b} + \frac{\sqrt{\Delta\left(v_{t-2}/\delta - \rho_{t-1}\right)} - \sqrt{\Delta\left(v_{t-1}/\delta - \rho_t\right)}}{b},$$

and noting that $\partial\rho_{t-1}/\partial v_{t-1} = 1$, we have

$$\frac{\partial m^*_{t-1,12}}{\partial v_{t-1}} = -\frac{\sqrt{\Delta}}{2}\frac{\delta\sqrt{(v_{t-1}/\delta - \rho_t)} + \sqrt{(v_{t-2}/\delta - \rho_{t-1})}}{\sqrt{(v_{t-1} - \delta\rho_t)}\sqrt{(v_{t-2} - \rho_{t-1}\delta)}} < 0.$$

This implies that $\left|\frac{\partial^2 m^*_{t-1,12}}{\partial\Delta\partial v_{t-1}}\right| > 0$.

A.5 Effects of a Temporary Tariff Change Under High Demand Uncertainty

Recall that, graphically, an increase in v_{t-1} shifts the interval $\overline{\epsilon}(z_t) - \underline{\epsilon}(z_t) = w_t - \rho_t$ from right to left relative to a fixed support of demand shock realizations of length 2Δ centered around zero. In the case of high demand uncertainty, when $\overline{\epsilon}(z_t) - \underline{\epsilon}(z_t) = w_t - \rho_t < 2\Delta$, an increase in v_{t-1} results in a unique path from regime (12) to regime (123) to regime (23), with $z^*_{t,12} \geq z^*_{t,123} \geq z^*_{t,23}$ (see Figure 5).

This path is the same as the one for low demand uncertainty, except that, since $\overline{\epsilon}(z_t) - \underline{\epsilon}(z_t) = w_t - \rho_t < 2\Delta$, regime (2) never arises but is replaced by regime (123) instead. In this regime, the firm accumulates inventory if demand is low, stocks out if demand is in an intermediate range, and engages in dual sourcing by purchasing domestically when demand turns out to be high.

Figure 6 plots z^*_t and $\hat{q}_t$ for the case of high demand uncertainty. The figure illustrates that the key result, namely that a change in v_{t-1} affects the optimal inventory more strongly than expected sales, continues to hold when demand uncertainty is high, including in regime (123) which now replaces regime (2).

Formally we can verify that the switch from regime (12) to (123) is at $\frac{v_{t-1}}{\delta} = \rho_t + \frac{(w_t-\rho_t)^2}{4\Delta}$, and the one from regime (123) to (23) at $\frac{v_{t-1}}{\delta} = w_t - \frac{(w_t-\rho_t)^2}{4\Delta}$. A temporary tariff change characterized by $dv_{t-1} \neq 0$ and $d\rho_t = 0$ implies

$$\frac{\partial z^*_{t,123}}{\partial v_{t-1}} = -\frac{\Delta}{b\delta\left(w_t - \rho_t\right)} < 0.$$

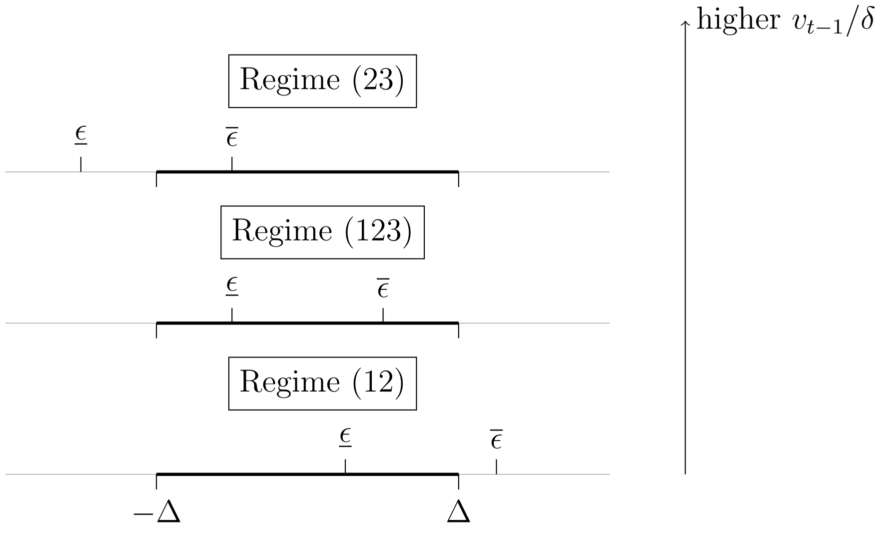

Figure 5: Trade protection path with high demand uncertainty

Moreover, we can show

$$\left|\frac{\partial z^*_{t,123}}{\partial v_{t-1}}\right| > \left|\frac{\partial \hat{q}_{t,123}}{\partial v_{t-1}}\right| = \frac{1}{2b\delta},$$

which follows from the fact that in this regime $w_t - \rho_t < 2\Delta$. In regime (123), we can follow the same reasoning as in the other cases to conclude that a temporary tariff change affects $m_{t-1,123}$ more than $\hat{q}_t$.

A.6 Effects of a Permanent Tariff Change

How do our results change if the tariff change is not temporary but permanent? This implies a simultaneous change in v_{t-1} and v_t (and hence ρ_t) in all periods t, such that $dv_{t-1} = d\rho_t = d\tau$. There are two effects: a short-term adjustment effect and a permanent one. The short-term effect of a tariff change is qualitatively similar to the effects shown in Figures 4 and 6 for a temporary tariff change. The only differences occur in regimes (12) and (123) as these are the only ones in which the optimal inventory is affected by ρ_t and hence by the value of excess inventory in period t. Since a permanent tariff increase raises ρ_t, expected imports fall less than in the case of a temporary tariff rise. However, it is still the case that a change in the permanent tariff has stronger effects on optimal inventory than on expected sales. In particular, given that a permanent change in the tariff implies

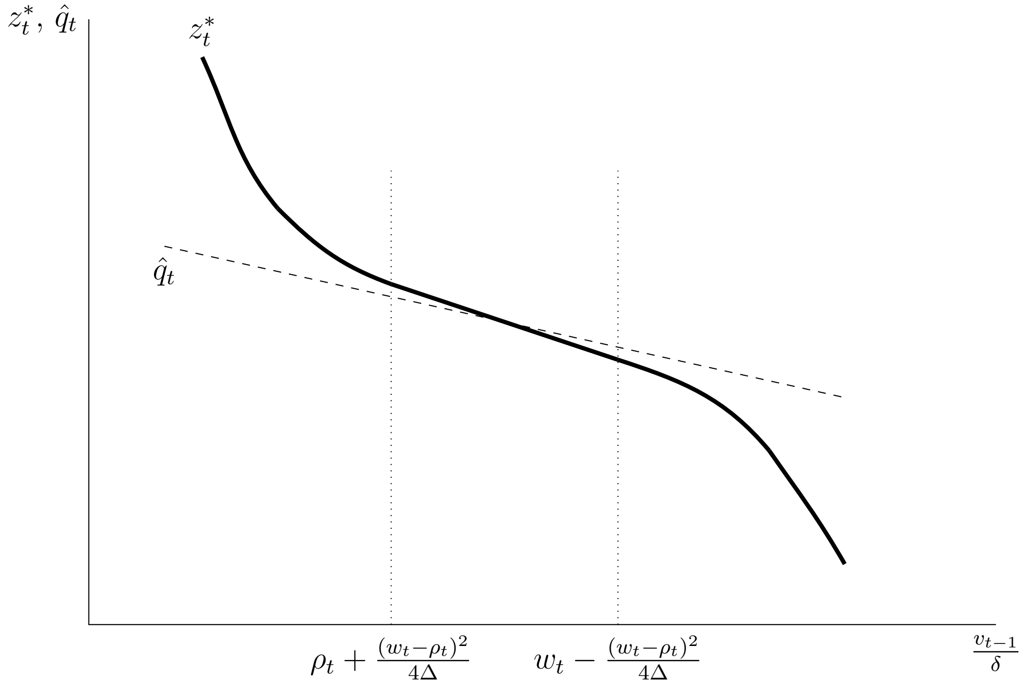

Figure 6: z_t^* and $\hat{q}_t$ – High Demand Uncertainty

$d\tau = dv_{t-1} = d\rho_t \neq 0$, we find

$$\frac{\partial z^*_{t,12}}{\partial \tau} = -\frac{1}{2b}\left(\frac{(1-\delta)\sqrt{\Delta}}{\delta\sqrt{v_{t-1}/\delta - \rho_t}} + 1\right) < 0, \tag{A.7}$$

$$\frac{\partial z^*_{t,123}}{\partial \tau} = -\frac{1}{4b}\left(\frac{4\Delta\left(v_{t-1} - \rho_t + (1-\delta)w_t\right)}{\delta\left(w_t - \rho_t\right)^2} + 1\right) < 0, \tag{A.8}$$

$$\frac{\partial z^*_{t,2}}{\partial \tau} = \frac{\partial z^*_{t,2}}{\partial v_{t-1}} < 0, \tag{A.9}$$

$$\frac{\partial z^*_{t,23}}{\partial \tau} = \frac{\partial z^*_{t,23}}{\partial v_{t-1}} < 0. \tag{A.10}$$

Consider regime (12). Given that in this regime $\Delta > v_{t-1}/\delta$ and hence $\sqrt{\Delta} > \sqrt{\frac{v_{t-1}}{\delta} - \rho_t}$, we can establish that

$$\left|\frac{\partial z^*_{t,12}}{\partial v_{t-1}}\right| > \left|\frac{\partial z^*_{t,12}}{\partial \tau}\right| > \left|\frac{\partial \hat{q}_{t,12}}{\partial \tau}\right| = \frac{1}{2b\delta}.$$

In regime (2) we obtain:

$$\left|\frac{\partial z^*_{t,2}}{\partial v_{t-1}}\right| = \left|\frac{\partial z^*_{t,2}}{\partial \tau}\right| = \left|\frac{\partial \hat{q}_{t,2}}{\partial \tau}\right| = \frac{1}{2b\delta}.$$

In regime (23), where $\Delta > (w_t - v_{t-1}/\delta)$, we have:

$$\left|\frac{\partial z^*_{t,23}}{\partial v_{t-1}}\right| = \left|\frac{\partial z^*_{t,23}}{\partial \tau}\right| > \left|\frac{\partial \hat{q}_{t,23}}{\partial \tau}\right| = \frac{1}{2b\delta}.$$

In regime (123), we can show

$$\left|\frac{\partial z^*_{t,123}}{\partial v_{t-1}}\right| > \left|\frac{\partial z^*_{t,123}}{\partial \tau}\right| > \left|\frac{\partial \hat{q}_{t,123}}{\partial \tau}\right| = \frac{1}{2b\delta},$$

where the first inequality requires

$$\frac{4\Delta\left(w_t - \frac{v_{t-1}}{\delta}\right) - (w_t - \rho_t)^2}{4b\left(\rho_t - w_t\right)^2} > 0,$$

which follows from the fact that in regime (123) we require $-\Delta < \underline{\epsilon}(z_t) = 2bz_t - a + \rho_t$ which can be reduced to

$$4\Delta\left(w_t - \frac{v_{t-1}}{\delta}\right) > (w_t - \rho_t)^2.$$

The second inequality requires

$$\frac{4\Delta\left(v_{t-1} - \rho_t + (1-\delta)w_t\right) - (2-\delta)(w_t - \rho_t)^2}{4b\delta(w_t - \rho_t)^2} > 0.$$

The numerator can be rewritten as

$$4\Delta\left(v_{t-1} - \rho_t\right) - (w_t - \rho_t)^2 + (1-\delta)\left(4\Delta w_t - (w_t - \rho_t)^2\right)$$

Adding and subtracting $4\Delta(1-\delta)v_{t-1}/\delta$, the above expression becomes

$$\left[4\Delta(v_{t-1}/\delta - \rho_t) - (w_t - \rho_t)^2\right] + (1-\delta)\left[4\Delta(w_t - v_{t-1}/\delta) - (w_t - \rho_t)^2\right].$$

It is unambiguously positive because the two expressions in square brackets are positive; the first one coming from the condition $\Delta > \overline{\epsilon}(z_t)$ and the second one from the condition $-\Delta < \underline{\epsilon}(z_t)$.

In addition, a permanent increase in the tariff now decreases directly $\overline{\epsilon}(z_t) - \underline{\epsilon}(z_t) =$

$w_t - \rho_t$. This tends to encourage a regime switch from (2) to (123), which means that, as the firm reduces inventory in response to a permanent tariff increase, it is more likely to rely on domestic sourcing when demand turns out to be high rather than to stock out. Given the effects of a permanent tariff change on the optimal inventory, it is straightforward to verify the effects on the volume of imports.

Not surprisingly, it is also the case that a mean-preserving increase in demand uncertainty magnifies the effects of a permanent tariff change on optimal inventory and import volume relative to expected sales. The underlying mechanism is the same as for a temporary tariff change: The greater is Δ, the more an increase in the tariff pushes the firm to increase its domestic sourcing share in regimes (23) and (123). In addition, a higher Δ makes regime (23) and (123) more likely to occur. Thus, here too, differences with the effects of a temporary tariff change are quantitative, not qualitative.

What is the permanent effect of this tariff change? This amounts to comparing optimal inventory, or expected import levels, across steady states with marginally different tariffs. In regime (123), a permanent increase in the tariff affects expected imports $\hat{m}_{t-1,123}$ more strongly than $\hat{q}_t$ and hence more strongly than without stockout avoidance, as the firm changes its dual sourcing mix toward greater domestic sourcing, which means cutting imports. In regime (12), the steady-state expected imports in any period $t-1$, $\hat{m}_{t-1,12}$, must be equal to expected sales $\hat{q}_t$. If expected imports were greater, the firm would accumulate excess inventory over time, which is clearly not an optimal strategy.