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journal homepage: [www.elsevier.com/locate/iref](http://www.elsevier.com/locate/iref)Ambiguity and the multinational firm<sup>☆</sup>Kit Pong Wong<sup>\*</sup>

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## ABSTRACT

This paper examines the optimal production and hedging decisions of the multinational firm under exchange rate uncertainty when the multinational firm possesses smooth ambiguity preferences. Ambiguity is modeled by a second-order probability distribution that captures the multinational firm's uncertainty about which of the subjective beliefs govern the exchange rate risk. Ambiguity preferences are modeled by the (second-order) expectation of a concave transformation of the (first-order) expected utility of home currency profit conditional on each plausible subjective distribution of the exchange rate risk. Within this framework, we show that the separation and full-hedging theorems are robust to the incorporation of ambiguity and ambiguity preferences. The presence of the currency hedging opportunity induces the multinational firm to produce more and sell less at home, and export more abroad. When the forward exchange rate is biased, we derive necessary and sufficient conditions under which the multinational firm optimally opts for a forward position that is closer to a full-hedge in response to either the introduction of ambiguity or greater ambiguity aversion.

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## 1. Introduction

Multinational firms take exchange rate risk management seriously. In an extensive survey of *Fortune* 500 firms, Jesswein, Kwok, and Folk (1995) document the extent of knowledge and use of exchange rate risk management products by these firms. They show that currency forward contracts are the most popular hedging instruments that are adopted by 93.1% of respondents of the survey. The next commonly used hedging instruments are foreign currency swaps (52.6%) and over-the-counter currency options (48.8%). Recent innovative exchange rate risk management products such as compound options (3.8%) and look-back options (5.1%) are among the least extensively used hedging instruments. The Jesswein et al. (1995) survey suggests that most multinational firms meet their exchange rate risk management needs by relying solely on currency forward contracts that are not supplanted by more complicated innovations.<sup>1</sup>

The study of the multinational firm under exchange rate uncertainty has been the subject of considerable research in decision making under uncertainty (Broll, 1992; Broll & Zilcha, 1992; Choe, Lien, & Yu, 2015; Katz & Paroush, 1979; Kawai & Zilcha, 1986; Lien & Wong, 2005; Meng & Wong, 2007; Viaene & Zilcha, 1998; Wong, 2012, 2013). The extant literature assumes that the multinational firm's preferences admit the standard von Neumann–Morgenstern expected utility representation. When the multinational firm has access to a forward market for currency hedging purposes, two celebrated results emanate. First, the separation theorem states that the multinational firm's production and export decisions depend neither on the risk attitude of the

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<sup>1</sup> In a survey conducted by the Wharton School of the University of Pennsylvania, 83% of large firms hedge against commodity, currency, and interest rate risk, whereas only 45% of medium firms and 12% of small firms do so. Multinational firms are clearly in the category of large firms. See Bodnar, Hayt, and Marston (1998).

multinational firm, nor on the incidence of the exchange rate uncertainty. Second, the full-hedging theorem states that the multinational firm fully hedges against its risk exposure to the exchange rate uncertainty should the forward market be unbiased.

In reality, multinational firms may not be able to unambiguously assign a probability distribution that uniquely describes the exchange rate risk. To this end, we define uncertainty in the sense of Knight (1921) to be made up of two components, risk and ambiguity.<sup>2</sup> Risk aversion is the aversion to a set of outcomes with a known probability distribution. Ambiguity aversion is the additional aversion to being unsure about the probabilities of outcomes. Dated back to the Ellsberg's (1961) paradox, ambiguity has been alluded to the violation of the independence axiom, which is responsible for the decision criterion being linear in the outcome probabilities.<sup>3</sup> The distinction between the known–unknown and the unknown–unknown is relevant since individuals appear to prefer gambles with known rather than unknown probabilities. Indeed, ample experiments (Chow & Sarin, 2001; Einhorn & Hogarth, 1986; Sarin & Weber, 1993) and surveys of business owners and managers (Chesson & Viscusi, 2003; Viscusi & Chesson, 1999) have documented convincing evidence that ambiguity aversion prevails.

Klibanoff, Marinacci, and Mukerji (2005) have recently developed a powerful decision criterion known as “smooth ambiguity aversion” that is compatible with ambiguity averse preferences under uncertainty (hereafter referred to as the KMM model). The KMM model features the recursive structure that is far more tractable in comparison to other models of ambiguity such as the pioneering maxmin expected utility (or multiple-prior) model of Gilboa and Schmeidler (1989).<sup>4</sup> Specifically, the KMM model represents ambiguity by a second-order probability distribution that captures a decision maker's uncertainty about which of the subjective beliefs govern the underlying risk. The KMM model then measures the decision maker's expected utility under ambiguity by taking the (second-order) expectation of a concave transformation of the (first-order) expected utility conditional on each plausible subjective distribution of the underlying risk. This recursive structure creates a crisp separation between ambiguity and ambiguity aversion, i.e., between beliefs and tastes, which allows us to study these two attributes independently. Another nice feature of the KMM model is that we can apply the conventional techniques in the decision making under uncertainty in the context of ambiguity (Alary, Gollier, & Treich, 2013; Cherbonnier & Gollier, 2015; Gollier, 2011; Snow, 2010, 2011; Taboga, 2005; Treich, 2010; Wong, 2015, in press).

In this paper, we incorporate the KMM model into the multinational firm under exchange rate uncertainty à la Broll and Zilcha (1992) by assuming that the multinational firm possesses smooth ambiguity preferences. Specifically, the multinational firm produces in the home country and sells its output in both the home and foreign markets. The multinational firm is ambiguous about the distribution of the random spot exchange rate between the home and foreign currencies. To hedge against the exchange rate risk, the multinational firm can trade the foreign currency forward at a predetermined forward exchange rate. We show that the separation and full-hedging theorems are robust to the incorporation of ambiguity and ambiguity preferences. As long as the multinational firm optimally sells the foreign currency forward, we show that the availability of the currency hedging opportunity induces the multinational firm to produce more and sell less at home, and export more abroad. When the forward exchange rate is biased in that it is different from the objective expected spot exchange rate, we derive necessary and sufficient conditions under which the multinational firm optimally opts for a forward position that is closer to a full-hedge in response to either the introduction of ambiguity or greater ambiguity aversion. These necessary and sufficient conditions hold when the multinational firm's coefficient of relative risk aversion does not exceed unity and its subjective beliefs are ranked in the sense of first-order stochastic dominance.<sup>5</sup>

While most of the results in this paper are consistent with the findings of the extant literature under risk aversion, subtle differences arise when ambiguity and ambiguity aversion prevail. First, risk aversion does not allow for ambiguity so that the multinational firm's reaction to ambiguity cannot be studied. Second, we show that greater ambiguity aversion may induce the multinational firm to opt for a forward position that is further away from a full-hedge when the forward exchange rate is biased, which is in stark contrast to the case of greater risk aversion. These suggest that the distinction between risk aversion and ambiguity aversion and that between the known–unknown and the unknown–unknown are important considerations to better understand the behavior of the multinational firm.

The rest of this paper is organized as follows. Section 2 delineates the KMM model of the multinational firm under exchange rate uncertainty. Section 3 characterizes the solution to the model. Section 4 examines the effect of currency hedging on the multinational firm's production and export decisions. Section 5 examines how ambiguity and ambiguity aversion affect the multinational firm's optimal forward position. The final section concludes.

<sup>2</sup> Knight (1921) points out that ambiguity is fundamentally different from risk. Specifically, risk relates to objective uncertainty, where outcome probabilities are known or can be estimated with confidence. In contrast, ambiguity relates to subjective uncertainty, where outcome probabilities are unknown, and decision makers are not sure which estimated models are correct.

<sup>3</sup> A vivid description of the Ellsberg (1961) paradox is from Keynes (1921). Consider the following experiment with two urns, K and U. Urn K contains 50 red balls and 50 blue balls. Urn U contains 100 balls (all balls are either red or blue), but the exact numbers of red and blue balls are not disclosed. Subjects are asked to select from which urn they would like to draw a ball. They are rewarded if the color of their choice is drawn. In this experiment, subjects typically select urn K, revealing aversion to ambiguity. To see this, suppose that subjects believe that the probability of drawing a blue ball from urn U is  $p$ . Subjects should prefer to draw a red ball or a blue ball from urn U than from urn K, depending on whether  $p$  is smaller or greater than  $1/2$ , respectively. If  $p = 1/2$ , subjects should be indifferent between the two urns. Since subjects choose to draw from urn K, such paradoxical behavior can only be rationalized by allowing multiple priors to be held by subjects on urn U. See also Dillenberger and Segal (2015) and Machina (2014).

<sup>4</sup> Skiadas (2013) shows that smooth ambiguity preferences can be approximated by preferences admitting an expected utility representation in continuous-time or high-frequency models under Brownian or Poisson uncertainty.

<sup>5</sup> Barham, Chavas, Fitz, Salas, and Schechter (2014) document that the average coefficient of relative risk aversion is 0.8 in their sample of Midwestern grain farmers in the U.S., which is in line with the magnitudes of relative risk aversion found in many developing countries (Cardenas & Carpenter, 2008).

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