The Medieval Heavy Plow Hypothesis:
An Instrument of Agricultural Innovation, Population Growth, and Urbanization in Medieval Western Europe
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Medieval historian Lynn White Jr. argued in his 1962 monograph *Medieval Technology and Social Change* that the heavy plow's introduction to medieval Western Europe from the Slavic East and its further modifications by Western Europeans had a profound impact on agricultural productivity and techniques, population, and urban growth in the High Middle Ages. The following discussion aims to expand and confirm the validity of White's "heavy plow hypothesis" through the analysis of primary and secondary sources.[1]

Section one is a brief historical background on the heavy plow's origins, modifications and its impacts on agricultural productivity, techniques, and population growth that will provide the reader with an understanding of the subsequent sections of the discussion. Section two is a historiography of White's contribution that shows how historians have perceived White's technological hypothesis since its publication over fifty years ago and why I believe his findings should still be utilized. Section three explores the origins and technical details of the heavy plow through the analysis of primary source texts and images, such as medieval manuscripts, to pinpoint when the heavy plow was introduced to Western Europe and see if it matches up with White's work. This will also show if the heavy plow was present during the high medieval period of population increase. Section four discusses the heavy plow's impact on medieval European agricultural techniques and productivity. Lastly, in section five, a modern Danish scientific study and other secondary sources shows if the heavy plow accelerated population and urban growth during this period.

An Introduction to the Heavy Plow

The origins of the medieval heavy plow and the evolution of its technical details define how it impacted agricultural productivity and techniques as well as population and urban growth in the Early and High Middle Ages. The earliest iteration of the heavy plow, according to an account by the first-century CE Roman historian Pliny the Elder, appeared in the eastern regions of the Roman Empire, specifically Asia

[1] Lynn White, *Medieval Technology and Social Change* (London: Oxford University Press, 1962), 43-44, 50, and 78.

Minor. After the empire collapsed, this early heavy plow was introduced to the Slavic lands of Eastern Europe and Italy's Po Valley by the fifth century CE. From here, the Goths, a Western European Germanic tribe, made contact with the Slavs in the sixth century and took the design for the heavy plow back to Western Europe, where its technical details were greatly modified and became widely used by the beginning of the first millennium CE.[2]

This slow journey from the Roman Republic and Empire to Western Europe transformed the heavy plow's technical details. The plow that was used in the Roman Republic and early Empire was the *ard* (see Figure 1), designed for the dry and arid lands of the Mediterranean and pulled by two oxen. It used one primary cutting blade known as a *share* that dug up dirt without turning it and left a line of land between each furrow, which required a farmer to cross-plow[3] to cover the entire area. Later in this period, Pliny the Elder described the emergence of a rudimentary heavy plow, which was essentially an *ard* with the addition of wheels, which helped the share dig deeper into the ground. After the Roman Empire fell, this early heavy plow made its way to the Slavic lands of Eastern Europe by the fifth century, where its design traveled to Western Europe by way of the Goths in the sixth century. Here, Western Europeans transformed this heavy plow into its ultimate form by modifying its cutter to work with the wet and heavy soils of their region. They replaced the antiquated share with three parts: coulter (cut soil vertically), moldboard (turned soil) and the plowshare (cut soil horizontally).[4] This new plow would be used throughout Western Europe by the beginning of the High Middle Ages.[5]

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[2] James B. Tschen-Emmons, *Artifacts from Medieval Europe* (Santa Barbara: Greenwood, 2015), 16-17; White, *Medieval Technology*, 42, 45, and 53; Joel Mokyr, *The Lever of Riches*: *Technological Creativity and Economic Progress* (New York: Oxford University Press, 1990), 32; Joseph and Frances Gies, *Cathedral, Forge and Waterwheel* (New York: HarperCollins, 1994), 44-45; Paul Gans, "The Heavy Plow," *The Medieval Technology Pages,* http://scholar.chem.nyu.edu/tekpages/heavyplow.html; "Luttrell Psalter," *Bl.uk,* http://www.bl.uk/onlinegallery/ttp/luttrell/accessible/introduction.html#content

[3] According to James B. Tschen-Emmons, cross-plowing refers to the *ard* (pre-heavy plow) practice of plowing in the opposite direction and angle to the original furrows to turn soil left untouched by its rudimentary share; *Artifacts from Medieval Europe,* 17. White argues that the coulter, moldboard, and plowshare of the early medieval heavy plow replaced this share, which eliminated the time consuming cross-plowing technique, and resulted in increased agricultural productivity; *Medieval Technology*, 43.

[4] See **Figure 1**

[5] White, *Medieval Technology*, 41-45 and 53; Jean Gimpel, *The Medieval Machine* (New York: Holt, Rinehart and Winston, 1974), 41; "The Heavy Plow," *The Medieval Technology Pages* http://scholar.chem.nyu.edu/tekpages/heavyplow.html; James B. Tschen-Emmons, *Artifacts from Medieval Europe* (Santa Barbara: Greenwood, 2015), 16-17; Thomas B.

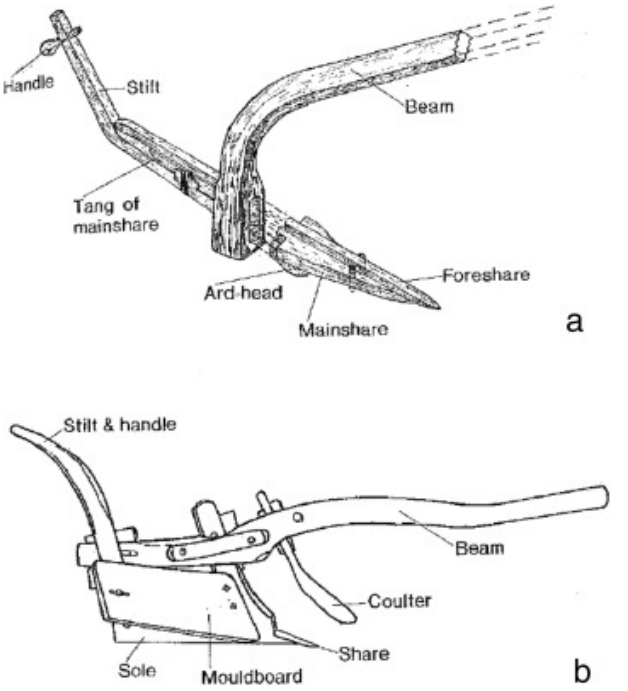

Figure 1: *Diagram of (a) ard and (b) heavy plow.* In Peter Fowler's *Farming in the First Millennium AD*. Cambridge: Cambridge University Press, 2002.

The emergence of the modified heavy plow had a massive impact on agricultural productivity and techniques in the Early and High Middle Ages in Western Europe in several ways. First, the new cutters eliminated cross-plowing[6], and this had several effects on practices and productivity: fields could now be larger and cultivated much faster than before since a farmer had to plow them only once, and it led to the invention of the harrow, which mixed seeds into the soil and flattened the ground behind the plow. Second, this new plow allowed farmers to expand their cultivation to the previously indomitable heavy and wet dirt that the ard could not work through, since it was designed for lighter soils. This also

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Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics,* August 2015.
http://www.sciencedirect.com.ezproxy1.library.arizona.edu/science/article/pii/S0304387815000978; Georges Comet, *Oxford Dictionary of the Middle Ages,* "Ploughs and Ploughing," Oxford: Oxford University Press, 2010; "Medieval Sourcebook: The Dialogue Between Master and Disciple on Laborers, c. 1000," *Fordham University: The Jesuit University of New York,* http://legacy.fordham.edu/Halsall/source/1000workers.asp.

[6] For a definition of cross plowing, refer to note 4.

led to vastly improved crop yields since these areas were rich with nutrients. Lastly, the heavy plow also brought about the medieval cooperative farming, or manorial, system, since it required the use of eight oxen, which forced peasants to bring their resources together as a single peasant did not have the means to own this many oxen.[7]

The heavy plow contributed to the accelerated population and urban growth that Western Europe experienced in the Early and High Middle Ages. Before the introduction of the heavy plow into Western Europe, settlers were confined to light soil regions, since the antiquated ard could not clear areas that had dense soil or were forested. Once the heavy plow was introduced, however, it made small work of these areas and opened them up for cultivation and settlement. Early medieval Germany, for example, experienced increased population growth primarily due to the heavy plow opening new and fertile lands that produced nutrient-rich food and offered new areas for urbanization. In addition, the heavy plow's ability to clear these productive fields for settlement in the High Middle Ages resulted in forty percent of the urban centers that emerged in Denmark and fifteen percent of those that emerged in Europe.[8] Other possible influences on population and urban growth in this period include a dry and warm climate and new protein-rich crop varieties that fertilized the ground.[9]

Historiography

In *Medieval Technology and Social Change,* Lynn White Jr. argued that technological innovations, such as the heavy plow, resulted in major social and economic change in the Middle Ages. Since its publication, technological historians have embraced as well as vilified this monograph through reviews, articles, scientific studies and books. The following historiography will explain why this has occurred by analyzing a section of White's monograph as well as examining how later historians and reviewers have interpreted his work after its publication. Specifically, it

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[7] An average peasant normally owned no more than three oxen. Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics,* August 2015; Mokyr, *The Lever of Riches,* 33; Gimpel, *The Medieval Machine,* 40-43; White, *Medieval Technology,* 41-45 and 54; Roy C. Cave and Hertbert H. Coulson, *A Sourcebook for Medieval Economic History* (New York: Biblo and Tannen Press, 1965), 38.

[8] Include citation to Danish study?

[9] Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics,* August 2015; White, *Medieval Technology,* 41-45 and 54; Gimpel, *The Medieval Machine,* 30-31, 40-43 and 51-52.

will explore White's technological theory on the origins of the medieval agricultural revolution and the economic, population and urban growth that he argues ensued. Ultimately, this historiographical review will show if White's arguments and evidence have held up over the past fifty-four years.[10]

In chapter two, White discusses how a medieval agricultural revolution was created almost solely by the introduction of new technologies in Western and Northern Europe: the heavy plow, horse harness and shoe, and the three-field crop rotation system. For all four, he explains their origins, evolution of technical details, and how the advantages of these new inventions contributed to the medieval agricultural revolution, which he claims resulted in increased population and urbanization.[11]

To support his claims, White utilizes a mix of primary and secondary sources, which he sometimes closely analyzes but other times merely cites without discussion. He also uses philology, the study of the historic development of language, as a primary source. In addition, he warns his readers that since the history of technology at the time was so underdeveloped, some of his work will undoubtedly have errors, and calls on historians to develop this history. This shows that White does not view his work as the final word but as a startup for new research. When discussing the heavy plow, for example, he explains its origins and technical details through accounts by the first-century CE Roman historian Pliny the Elder, archeological remains and philology. He also explains that other historians should research ridges created by the heavy plow, since this would pinpoint where it was used.[12]

In 1963, a year after the book was published, several reviews of it appeared in academic journals. Two of these will be discussed here. The first one titled "Technical Determinism: The Stirrup and the Plough" by English medieval historians P.H. Sawyer and R.H. Hilton is a primarily negative review of White's work. These authors argue that White puts too much certainty into archaeological dating, his linguistic evidence is not historical, he does not closely analyze cited source material, ignores sources that are contrary to his timeline and thesis, cites evidence that is great for future research but is fragile and difficult to trace, and that he only cites secondary sources. Thus, they believe that his study does not

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[10] White, preface, v-vi.

[11] Lynn White, *Medieval Technology and Social Change* (London: Oxford University Press, 1962), 41-44, 49, 53, 55.

[12] White, 42, 49, 55; Joseph Needham, "Reviewed Work: Medieval Technology and Social Change by Lynn White," *Isis* 54, No.3 (1963): 419-420.

establish technology as the catalyst for the medieval agricultural revolution and the resulting population and urban growth.[13]

Some of the points Hilton and Sawyer make in their review are well-founded while others are outright false. It is true that White does sometimes cite sources that are fragile. For example, when he discusses the emergence of iron mines in medieval Europe, he cites an account from a novelist and no other sources. However, their claims that White cites only secondary sources[14] and does not establish technology as the instigator of the medieval agricultural revolution are ludicrous for several reasons. White routinely cites primary sources, including the writings of Walter of Henley and Pope Urban II and illuminated manuscripts.[15] Second, White never claimed that his was a definitive account of the advance of medieval agriculture and its impact on population and urban growth. He admits that this history was extremely underdeveloped and had errors, which is why he routinely calls on historians to develop philological and archeological sources and left an impressive bibliography for them to work from.[16]

Joseph Needham, a renowned English scholar of science and technology, penned the second 1963 review of White's monograph. In this short but well-balanced review, Needham primarily praises White's work and mentions a few disagreements with some of his findings. He also discounts negative reviews. For example, he likes that White's thesis is clear and simple, and states that the book is "indispensable" for future scholars to work from since it provides "bibliographical mine galleries" of

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[13] R.H. Hilton and P.H. Sawyer, "Technical Determinism: The Stirrup and the Plough," *Past & Present*, No. 24 (1963): 92-94, 97 and 100.

[14] The statement made by Sawyer and Hilton that "Mr. White relies on secondary works entirely" (page 100) is again proven false by the fact that earlier in the review the authors mention that White's use of illuminated manuscripts and archaeological evidence (both primary sources) is "not very helpful." This mistake makes their overall argument appear very weak.

[15] Other examples of primary source citations include Walter of Henley, a thirteenth-century English agriculturalist, who discusses the ox's advantage over the horse as a plow animal (page 62); Pope Urban II's Council of Claremont, which placed oxen, horses and men who knew how to operate plows under armed protection (page 63); and the *Domesday book* of 1086, which does not show horses as plow animals and thus supports his argument that horses were utilized by farmers after 1086(page 64). The argument that White relied "entirely" on secondary works to support his thesis is a clear falsehood.

[16] R.H. Hilton and P.H. Sawyer, "Technical Determinism: The Stirrup and the Plough," *Past & Present*, No. 24 (1963): 92-94, 97 and 100; Joseph Needham, "Reviewed Work: Medieval Technology and Social Change by Lynn White," *Isis* 54, No.3 (1963): 419; White, 40.

primary and secondary sources.[17] In addition, he argues that White's evidence is so concrete that most of his thesis will not be overturned. He states that the only aspect of White's work that he disagrees with is his conclusions on the technical details and origins of medieval innovations like the crankshaft and the horse harness. Also, Needham, unlike Sawyer and Hilton, recognized that White's monograph was not a definitive account of how medieval technological innovations caused social change, since he quotes White's statement about how research in this field at the time was underdeveloped and that his work will undoubtedly have errors. Additionally, Needham blasts Sawyer and Hilton for falsely arguing that White only used secondary source material.[18]

In the 1970s, it is clear that White's findings were accepted by scholars, who expanded his initial research, which is exactly what he and Needham wanted. A great example of this renewed research is historian Jean Gimpel's 1974 *The Medieval Machine,* which discusses medieval mining, labor and science, and includes a chapter that describes the medieval agricultural revolution. In this section, Gimpel routinely cites White's findings as a model, but he expands and improves White's original research in several ways. First, he thoroughly analyzes source material, such as Walter of Henley's writing, which White cited but did not discuss in depth. Second, he agrees with White's findings on medieval technological innovations and their effects on agriculture and population growth, but he expands White's work with new and original research (e.g., he provides statistical evidence to show how the heavy plow increased grain yields,).[19] Lastly, in addition to stating that technological innovations were the primary result of the medieval agricultural revolution, he expands White's thesis by arguing that climate, universities, and the emerging wool and wine industries were also major contributors.[20]

In 1997, a collection of essays edited by historians Grenville Astill and John Langdon titled *Medieval Farming and Technology* was published, which includes an introduction that succinctly describes how scholars

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[17] Joseph Needham, "Reviewed Work: Medieval Technology and Social Change by Lynn White," *Isis* 54, No.3 (1963): 419-420.
[18] Ibid.
[19] The statistical evidence that Gimpel provides shows that grain yields increased on average by almost double: 2.5 to 4.0 measures per every grain sown (page 43). This is great supporting evidence for his and White's argument, but he does not provide the reader with an in-text citation (or any citation for that matter) for this source so it can be easily read and analyzed by future historians.
[20] Jean Gimpel, *The Medieval Machine* (New York: Holt, Rinehart and Winston, 1974), 29-30, 38-45, 47, and 56.

viewed White's and Gimpel's theories since the late 1970s. Soon after Gimpel's book was published in 1974, Marxist scholars opposed this "technophilic interpretation" and argued that lords and peasants did not want to invest in upgrading medieval technology.[21] Michael Postan later reinforced this thesis by arguing that population growth was "inexorable" and in the Middle Ages went through a cycle of rising and dwindling based on land use and the amount of food supplies available.[22] European scholars accepted this until the 1980s when economist Ester Boserup argued that the growing medieval population made it difficult for farmers to keep up with demand, so innovations in agricultural technology to improve production were "a natural and almost inevitable response."[23] This new argument enlivened scholars to return to White's thesis and to continue expanding his initial research.[24]

In 2003, the journal *Technology and Culture* published a new review of White's 1962 monograph *Medieval Technology and Social Change* authored by Alex Roland. This review differed from previous ones in that its aim was to not just review White's work, but also to evaluate the work of past critical reviews to see if their charges were accurate and determine if scholars should still use White's work today. Roland argues that most reviewers, and specifically Hilton and Sawyer, had an unjustifiably scathing and dismissive tone, "refuted arguments that White did not make, inferred motives that White did not manifest, and accused him of views he did not hold."[25] Roland also states that scholars were fearful of praising "technological determinism" (i.e., major historical changes caused by simple technological innovations) in the 1960s because they believed it would lead to its confirmation in the Cold War arms race, so they quickly shot down works like White's that used this thesis structure even if they presented a reasonable argument. Roland, however, did agree with some criticism of White's work. For instance, he argued that White sometimes ignored contradictory information that did not fit his argument and that he did not discuss, like Jean Gimpel, other factors that may have led to the medieval agricultural revolution and population growth, such as climate and universities.[26]

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[21] Grenville G. Astill and John Langdon, Medieval *Farming and Technology: the Impact of Agricultural Change in Northwest Europe* (Leiden: Brill, 1997), 1-4.
[22] Ibid.
[23] Ibid.
[24] Ibid.
[25] Alex Roland, "Once More into the Stirrups: Lynn White Jr., 'Medieval Technology and Social Change,'" Technology *and Culture* 44, No. 3 (2003): 578-581.
[26] Ibid., 581-583

After his review of the criticism, Roland's final evaluation of White's work is that it should still be used for several reasons. First, he states that the "broad outlines of his paradigms still stand," so they continue to be valid.[27] Second, it is still the best work out there on this topic and the only reason not to use it would be if a new and better history is published and replaces it. Lastly, Roland calls on historians to expand these arguments rather than discounting and criticizing them, since they remain viable.[28]

In 2015, the University of Southern Denmark paid heed to Alex Roland's call by conducting a scientific study published in the *Journal of Economic Developments* that expanded and tested Lynn's White's "heavy plow hypothesis." The study argues that the introduction of the heavy plow to Northern and Western Europe resulted in extraordinary population, economic, and urban growth between the ninth and thirteenth centuries. The study further states that this was the first time that this hypothesis was tested under scientific means and that the results agree with White's argument. Before showing these results, however, the authors provided information on the origins and technical details of the heavy plow, based primarily on White's findings and other recent works that confirm and expand his research, which shows that they viewed White's work as valid and acceptable.[29] After establishing this background, the study shows that tremendous urbanization, population and economic growth were confined to clay soil areas in Northern and Western Europe, which the heavy plow made inhabitable. They found that this implement was responsible for 41.6% of urbanization in Denmark and 14.9% in Europe as a whole. Like Gimpel, the study also states that universities and climate change were other factors in addition to technology.[30]

After reviewing and analyzing White's technological view of the medieval agricultural revolution as well as subsequent reviews, criticism, scholarly works, and studies, I argue that almost all of the criticism White received should be discounted, and that his arguments are mostly valid and acceptable. He believes they should be expanded and improved

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[27] Ibid., 583

[28] Ibid., 583-585.

[29] To show the evolution of shares, for example, the authors cite (page 136) the recent work (1987) of Henning, who determined that the heavy plow emerged in Eastern Europe between the seventh and tenth centuries. This confirms and expands upon White's linguistic evidence that the Slavs had the heavy plow in the seventh century.

[30] Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118 (January 2016): 133-136, 138, 141, 145, and 147.

upon by future scholars for several reasons. First, some of the criticism that White received was acceptable, such as Roland's belief that White needed to explain the other possible factors that led to the agricultural revolution, but the review by Sawyer and Hilton should be mostly discounted, since they made comments that were largely false, inferred issues with White's work that did not exist, and were blinded by Cold War politics, which made them unjustifiably prejudiced against White's thesis from the start. Second, since White's work was never meant to be a definitive account and some of it has been confirmed to be accurate, and because the general outline of his arguments still stands, it should be improved and expanded upon until a new work overtakes the prominence and accuracy of this work. Lastly, White's argument that the agricultural revolution was caused by technological innovations should be examined along with other possible social, political and economic factors to determine if it was primarily driven by technology or by a variety of forces.[31]

The subsequent discussion covering the heavy plow's origins, technical developments and impact on agriculture, population growth and urbanization will take the above historiography of White's work into account. It will seek to confirm, improve, and expand White's findings, as well as those of his reviewers and later technological historians, with new research and consider evidence that is not purely technological to see if the heavy plow truly had the large impact that White claims it had on agriculture and population. The new research includes primary source images, which White did not analyze, and recent secondary scientific studies and monographs that expand his original findings.

Charting the evolution of the heavy plow over time and region may at first seem unnecessary in relation to how the heavy plow led to new agricultural techniques and improved production in the medieval agriculture revolution or its involvement in accelerating population growth and urbanization in the High Middle Ages, but it is actually extremely important and relevant. Knowing when the heavy plow evolved into its final and, according to White, most productive form with coulter, plowshare, and moldboard allows historians to see if these technical innovations were present and had an effect during this period of large agricultural, population and urban change. This will help

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[31] Alex Roland, "Once More into the Stirrups: Lynn White Jr., 'Medieval Technology and Social Change,'" Technology *and Culture* 44, No. 3 (2003): 578-585; Joseph Needham, "Reviewed Work: Medieval Technology and Social Change by Lynn White," *Isis* 54, No.3 (1963): 419-420.

determine if the heavy plow had the large impact that White and later historians state it did during these two events.[32]

The Heavy Plow in Medieval Sources

White's claims about the origin of the heavy plow and the evolution of its technical details from the Early to High Middle Ages are mostly valid. He argued that a rudimentary heavy plow appeared in Western Europe in the sixth century through the Goths' meeting with the eastern Slavs. He supports this argument by using philology: he states that the Goths would generally adopt superior items from the Slavs as well as the word associated with those objects. He shows that the Goths began to use the word *Carruca* (wheeled plough) in the early sixth century, which he believes marks the emergence of the heavy plow in Western Europe, since they did not use this word before this century and the previously used word was *hoha*, which relates to a wheelless scratch plow or hoe. White likely used this evidence because primary images and texts discussing the heavy plow from this period are scanty to none. White pinpoints the introduction of the heavy plow to early Medieval Western Europe through the use of this evidence, but it does not reveal when it became technically mature or when it came into widespread use across Western Europe.[33]

Later authors agree with and expand White's work by arguing that the medieval Western European heavy plow evolved from its possible rudimentary form[34] in the sixth century to a complete version with coulter, plowshare, and moldboard that was in widespread use by the eleventh century foreword. This argument is valid supported by medieval manuscript images of the heavy plow that date between 1000 and 1300 CE and a textual source from c. 1000 CE. The earliest extant images of medieval plows the author could find are two English manuscript depictions that date to the eleventh century and the early twelfth century. The eleventh-century depiction is from the *Harleian Manuscript*[35] and depicts a man wielding a wheelless scratch plow with a

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[32] White, 42-43.
[33] White, 50.
[34] Based on Henning's Slavic sixth-century archaeological findings and early eleventh century manuscript illustrations, the heavy plow before 1000 CE may have had a plowshare and coulter, but no moldboard, which seems to be a later development since earlier manuscript drawings do not depict it and an *Oxford Dictionary of The Middle Ages* article titled "ploughs and ploughing" states that the moldboard on English plows appeared between 900 and 1200 CE.
[35] See **Figure 2**

single share pulled by two oxen, and the twelfth-century image from the *Eadwine Psalter*[36] depicts the same. In the manuscript images from the subsequent eras, the author only found depictions of heavy plows and could find no further images of a scratch plow. This shows that farmers across medieval Europe began to drop the antiquated scratch plows once the heavy plow caught on, which supports scholars' claims that the heavy plow was in widespread use from the eleventh century onward. Because these scholars do not explain why the heavy plow suddenly became popular in this century, this would be good for future historians to study.[37]

Figure 2: *Harleian Manuscript*. 11th century. In J.B. Passmore's *The English Plough*. London: Oxford University Press, 1930.

[36] See **Figure 3**

[37] Gimpel, *The Medieval Machine,* 40-41; Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 135-137; *Harleian Manuscript,* 11th century, In J.B. Passmore's *The English Plough*, London: Oxford University Press, 1930; *Eadwine Psalter,* 12th century, In J.B. Passmore's *The English Plough*, London: Oxford University Press, 1930; Georges Comet, *Oxford Dictionary of the Middle Ages,* "Ploughs and Ploughing," Oxford: Oxford University Press, 2010.

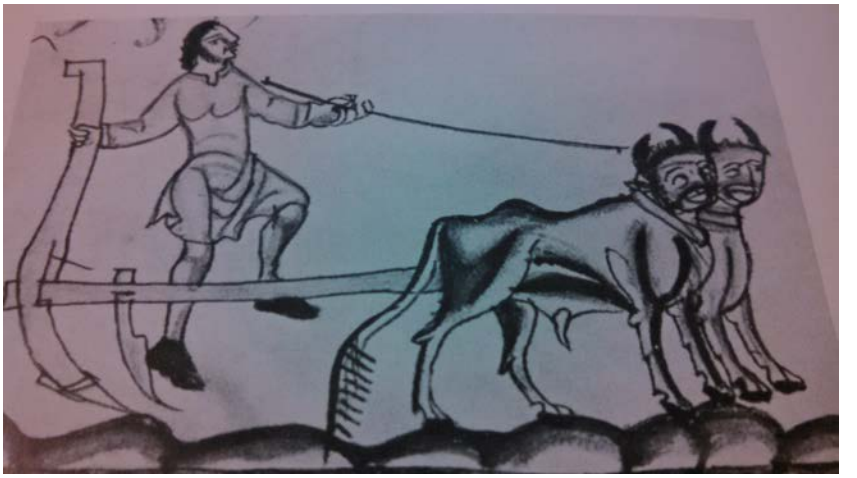

Figure 3: *Eadwine Psalter.* 12th century. In J.B. Passmore's *The English Plough*. London: Oxford University Press, 1930.

The manuscript images and textual sources from between 1000 and 1300 CE show how widespread the use of the heavy plow became and the evolution of its technical details. They also show a possible difference between English and continental European plow design. The circa 1000 CE "Dialogue Between Master and Disciple: on Laborers" reveals the possible technical development of the heavy plow at this time. In this writing, the master asks the disciple, or "plowman," what he does on an average day. The plowman responds that he attaches the oxen to his plow, which is equipped with a coulter and plowshare. That these are two of the three major parts of the heavy plow's innovations confirms that a matured form of this implement did exist in the eleventh century. The continental European and British manuscript images from this period onward show a gradual evolution of the wheeled heavy plow with regional variation. In an eleventh-century English and a twelfth-century Flemish manuscript, the technical details of the heavy plows correspond with the "Disciple" writing of the same period. The English *Cottonian Manuscript* from 1000 CE depicts a wheeled heavy plow with a coulter and plowshare (see Figure 4), and the 1175 CE Flemish *Le Vieil Rentier D'Audenarde* manuscript depicts a heavy plow with the same technical details (see Figure 5).[38] The plows depicted in these images support the

[38] An *Oxford Dictionary of The Middle Ages article* titled "ploughs and ploughing" states that the English heavy plow had wheels between 900 and 1200, but lost its wheels thereafter and turned into a swing plow. This statement is partly true, since the *Cottonian manuscript* wheeled heavy plow dates to this period, but it is false to argue that the English heavy

textual source and also show that the moldboard was possibly a later development, because almost all images after this period depict the heavy plow with this attachment.[39]

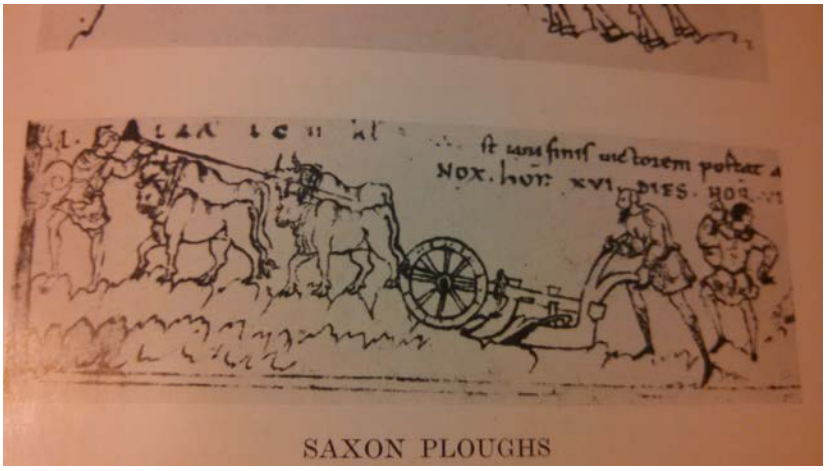

Figure 4: *Cottonian Manuscript.* Eleventh century. In J.B. Passmore's *The English Plough*. London: Oxford University Press, 1930.

plow later lost its wheels after this period, because an English manuscript image from the 15th century titled *Offices, Prayers for a Lady's Private Use* depicts a wheeled plow.

[39] Medieval Sourcebook: The Dialogue Between Master & Disciple: On Laborers, C. 1000," *Fordham University: The Jesuit University of New York,* http://legacy.fordham.edu/Halsall/source/1000workers.asp; *Le Vieil Rentier D'Audenarde: ms. 1175, fol. 156v: farming scene: det.: man plowing,* 1291-1302, manuscript, Bibliothèque royale de Belgique, http://www.artstor.org; *Cottonian Manuscript.* 11th century. In J.B. Passmore's *The English Plough*. London: Oxford University Press, 1930; Georges Comet, *Oxford Dictionary of the Middle Ages,* "Ploughs and Ploughing," Oxford: Oxford University Press, 2010; Georges Comet, *Oxford Encyclopedia of the Middle Ages,* Agricultural Techniques," Oxford: Oxford University Press, 2010.

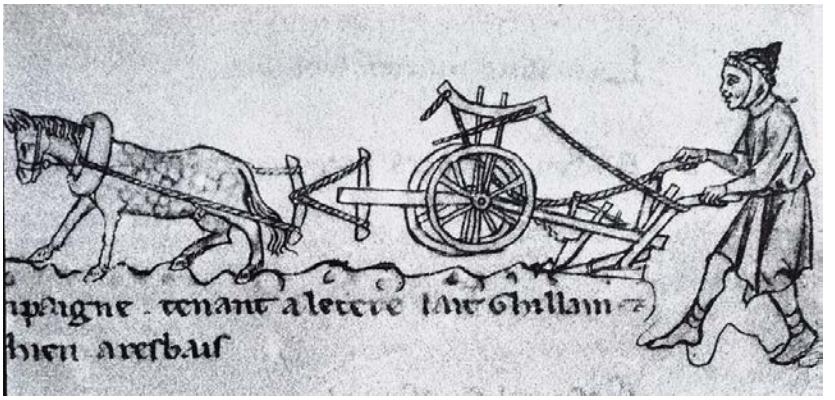

Figure 5: *Le Vieil Rentier D'Audenarde: ms. 1175, fol. 156v: farming scene: det.: man plowing.* 1291-1302. Manuscript. Bibliothèque royale de Belgique. In http://www.artstor.org

The heavy plows illustrated in Continental European manuscripts after the twelfth and into the fifteenth century primarily depict the fully evolved heavy plow with coulter, plowshare, and moldboard, while British manuscripts from the same period show the plow in various degrees of technical evolution, and this points to regional variation. An example of the Continental European development is the famous illuminated Flemish manuscript *Très Riches Heures du duc de Berry* that was created between 1409 and 1416 by the Limbourg Brothers. The "March" folio which depicts a man plowing a field with the fully evolved wheeled heavy plow discussed above (see Figure 6).[40] Oddly, the evolution of the British heavy plow in this period varies. A late thirteenth-century English manuscript from a Cistercian monastery depicts a diagram of a heavy plow with a coulter and plowshare but no wheels (see Figure 7). This is quite peculiar when two hundred years earlier the Cottonian plow had wheels. This wheelless design is repeated a century later in the famous *Luttrell Psalter* illuminated manuscript, which illustrates a heavy plow with a coulter, plowshare, and a moldboard (see Figure 8). The addition of the moldboard can mean either that the English heavy plow evolved evenly across Britain, or that

[40] Oddly, an *Oxford Encyclopedia of the Middle Ages* article titled "agricultural techniques" claims that all heavy plow lost their wheels in the 13th century and thereafter became a wheel less swing plow, but this is not accurate because several manuscript images created after this century show the heavy plow with wheels. The only ones that do not are from Britain, where extremely wet conditions in certain regions, according to White (page 46), may have required the use of a wheel less heavy plow.

certain regions were more advanced than others.[41] White states that heavy plows without wheels were used particularly for extremely wet soil, so it may have been a condition present in most of Britain since no other illustration from other regions had this type of heavy plow design. In the fifteenth century, a British manuscript titled *Offices, Prayers for a Lady's Private Use* shows a wheeled plow that is identical to the Flemish iteration from the same period (see Figure 9). This shows either that the British dropped the wheelless design or that this image depicts a certain region of England where a wheeled plow would be more acceptable.[42]

[41] An *Oxford Dictionary of The Middle Ages article* titled "ploughs and ploughing" states that the English heavy plow had developed a moldboard between 900 and 1200, which points to the plow evolving evenly throughout Britain.

[42] White, 46; *Cottonian Manuscript.* 11th century. In J.B. Passmore's *The English Plough*. London: Oxford University Press, 1930; Limbourg Brothers, *Tres Riches Heures du duc de Berry,* 1409-1416, manuscript, Encyclopedia Britannica Online; *Cistercian cartulary of nunnery of Nun Coton (now called Cotham)*, late 13th century, Manuscript. Bodleian Library, University of Oxford, http://www.artstor.org; *Luttrell Psalter*, 1325-1335, manuscript, http://www.bl.uk/onlinegallery/ttp/luttrell/accessible/page20lge.html; Georges Comet, *Oxford Dictionary of the Middle Ages,* "Ploughs and Ploughing" (Oxford: Oxford University Press, 2010).

Figure 6: Limbourg Brothers. *Tres Riches Heures du duc de Berry.* 1409-1416. Manuscript. In Encyclopedia Britannica Online.

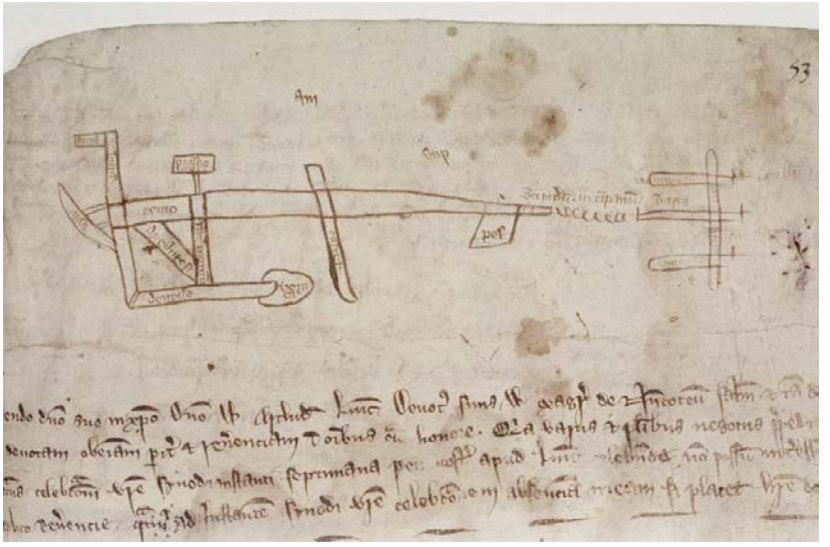

Figure 7: *Cistercian cartulary of nunnery of Nun Coton (now called Cotham)*. Late 13th century. Manuscript. Bodleian Library, University of Oxford. In http://www.artstor.org.

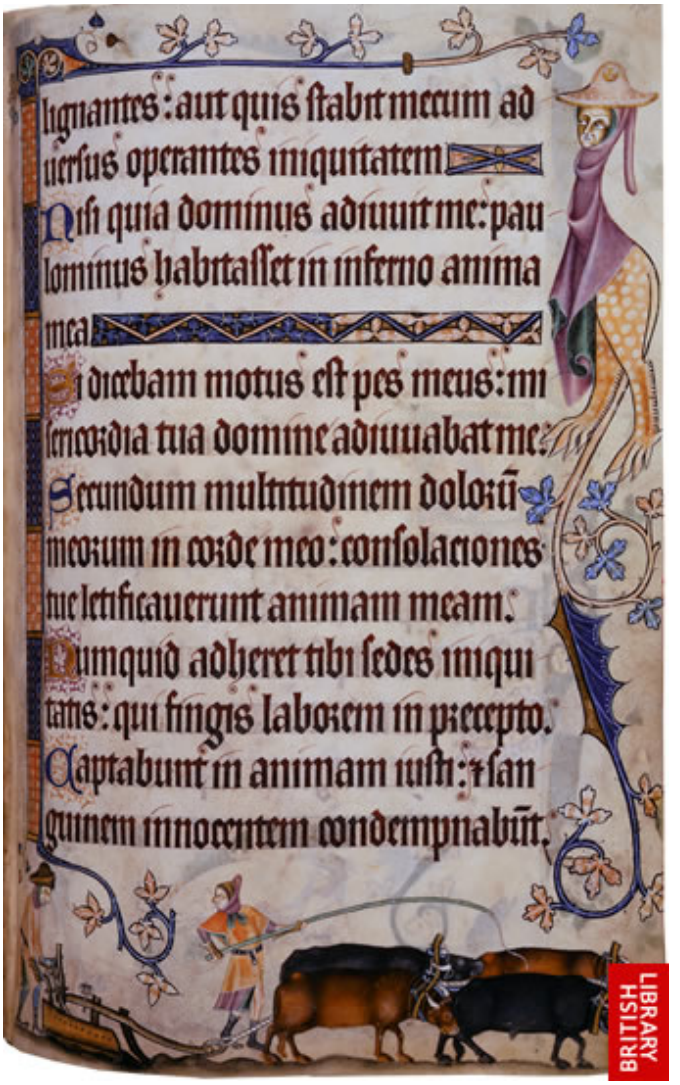

Figure 8: *Luttrell Psalter*. 1325-1335. Manuscript. In http://www.bl.uk/onlinegallery/ttp/luttrell/accessible/page20lge.html

Figure 9: *Offices, prayers for a lady's private use.* Late 15th century. Manuscript. Bodleian Library, University of Oxford. In http://www.artstor.org

As shown in the historiographical discussion of White's agricultural revolution thesis, most later historians have agreed with his "heavy plow hypothesis" in relation to the origins of the agricultural revolution and have expanded and confirmed this argument by providing statistics and suggested other possible factors beyond the plow. The following section/discussion will examine some of these sources in depth and compare them to White's original findings to see if these findings are valid. Primary source images of the heavy plow will also be discussed to determine if White's dates of the plow driven agricultural revolution are accurate. This will improve and expand parts of White's original argument.

In his 1974 monograph *The Medieval Machine*, Jean Gimpel discusses the origins and innovations of the medieval agricultural revolution. He argues that new agricultural technology, the horse, a warm climate, legumes, and the wool and wine industries caused the revolution. Gimpel agrees with White's theory that the increased power potential of the horse as compared to oxen, the fertilizing properties of legumes, and innovations in agricultural technology were behind the agricultural revolution and that the heavy plow was primarily responsible for the revolution's advances. He also expands this argument

by claiming that a warmer climate and the wool and wine industries were also important factors.[43]

In Gimpel's discussion of the heavy plow's evolution and the period of warm climate in Western Europe, the dates he presents agree as well as conflict with White's dating of the heavy plow's emergence. Gimpel states that the complete heavy plow emerged at the end of the tenth century whereas White argues that it was introduced to Western Europe during the sixth. Here, the evidence supports Gimpel's claim better than White's since extant textual and manuscript illustrations make clear that the advanced heavy plow was realized around 1000 CE. Despite the fact that the author, as well as White, could not find a text or illustration before this date, White's argument that it appeared around the sixth century could still be considered valid since his philology evidence is convincing as well as Henning's archaeological remainsof Slavic heavy plow shares,[44] but they are the only two primary sources that discuss the heavy plow before 1000 CE. This also creates another controversy: did the agricultural revolution start in the sixth century or at the end of the ninth? White's technological viewpoint would say the sixth, since the Goths in Germany, who had recently adopted the plow from the Slavs, experienced large population growth, whereas Gimpel's climate argument believes it would be the ninth since he makes clear that the heavy plow was only extremely influential because of the warm climate that emerged in this century. Without it, he implies it faltered.[45]

The authors of the previously mentioned 2015 study conducted by the University of Southern Denmark argue that the heavy plow increased agricultural productivity and introduced new techniques, which agrees with the findings that White made fifty years earlier. They state that the heavy plow allowed farmers to access nutrient rich soil, controlled weed growth, allowed settlement and cultivation of previously inaccessible land, saved time, and increased productivity. They also agree with Gimpel that the period of warm climate between 750 and 1300 may also have been a factor in improving agricultural productivity.[46]

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[43] Gimpel, *Medieval Machine,* 30-32, 45-48, and 51.

[44] Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 136.

[45] White, 50 and 54; Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 136; Gimpel, *Medieval Machine,* 30-32, 45-48, and 51.

[46] Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 133-136, and 145; Gimpel, *Medieval Machine,* 30-31.

As for the dating of the emergence of the heavy plow and the ensuing agricultural revolution created by its technical advantages, the authors of this study agree with both White and Gimpel. They agree with White's findings that the heavy plow was present in the Slavic lands around the seventh century when the Goths are said to have adopted it, because they cite Henning who found archeological evidence of Slavic heavy plow shares that date to this period. This shows that the agricultural revolution may have been occurring at a smaller scale before its widespread adoption across Europe around 1000 CE. They agree with Gimpel's findings in that they cite primary source images and high-backed ridges (ridges made by heavy plows) that seem to support that the heavy plow made its widespread European debut around 1000 CE. Like Gimpel, they use this same evidence to show that the larger agricultural revolution occurred in the High Middle Ages.[47]

In light of this evidence, White's original findings are still valid in several facets. First, Gimpel's argument that a warm climate was crucial to the heavy plow's success is somewhat specious when one considers that the absence of the heavy plow with a warm climate may not have brought about the widespread agricultural revolution in the High Middle Ages since the technological advances of this device would not have been present to improve agricultural productivity and techniques. Second, White's argument that the heavy plow emerged in Western Europe in the sixth century and started the medieval agricultural revolution in this same period is valid, since White's own philological evidence and the Danish study's presentation of Henning's Slavic archaeological findings show that this advanced plow was probably present at this time. However, the author does believe that this early medieval agricultural revolution was small and not widespread, since there is far more evidence for the high medieval revolution in the form of primary source images and texts that discuss the plow from countries all over Europe and the high-backed ridges discussed in the Danish study date to 1000 CE. These later findings expand White's original argument, but do not refute it. This analysis of primary and later secondary sources is similarly going to be used when discussing the heavy plow's effect on high medieval population growth and urbanization in Western Europe.[48]

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[47] Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 133-136, and 145; White, 50 and 53; Gimpel, *Medieval Machine,* 40-41.
[48] Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 133-136, and 145; White, 50 and 53; Gimpel, *Medieval Machine,* 30-31.

Impacts of the Heavy Plow

As previously mentioned, White argues that the heavy plow ushered in tremendous population growth and urbanization upon its introduction in the Early and High Middle Ages in Western and Northern Europe. The following discussion will test this claim and expand it by analyzing scholarly monographs, articles, and studies on medieval population growth to see what they consider to be the main catalyst of this growth and other factors that influenced it in addition to the heavy plow. Also, an analysis of primary source manuscript illustrations and text will show if the fully evolved heavy plow was present during this period of impressive population growth and urbanization.[49]

To understand why the High Middle Ages experienced a population and urban boom in Western Europe, White's and other scholars' beliefs on the state of population in the Early Middle Ages need to be addressed first. White argued that the introduction of the heavy plow into Western Europe via the Goths in the sixth century caused a population boom to occur in Germany. White's philological evidence and Henning's archaeological evidence show that the heavy plow was present and operating at this time. However, this early medieval population boom, like the agricultural revolution, should be viewed as a small scale development that occurred primarily in Germany and possibly the Slavic East, since the myriad primary source manuscript images that depict the heavy plow and support a widespread population increase across Europe do not appear until the High Middle Ages. Also, other scholars consider the Early Middle Ages to be an era of restricted population growth because of the prevalence of war, disease, and bad weather, which makes it even more likely that the population boom White claims occurred in Germany and possibly in the Slavic East was on a small scale.[50]

Although White's argument for heavy plow-induced population growth and urbanization in the Early Middle Ages is not persuasive due to a lack of primary source evidence and the fact that the period was known for stunted demographic growth, it is a very strong theory for the impressive growth that marks the High Middle Ages in Western Europe. White claimed that the agricultural revolution, with the heavy plow as its main catalyst, that occurred in the Early Middle Ages caused the High

[49] White, 42-44 and 78; Gimpel, *Medieval Machine,* 40.

[50] White, 50 and 54; Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 136; David Nicholas, *Oxford Dictionary of the Middle Ages,* "Demography and Population," Oxford: Oxford University Press, 2010.

Middle Ages to be a period of "rapid urbanization" and population growth. Scholarly studies and primary source manuscript images heavily support this theory.[51]

One of the most important secondary sources that supports and expands White's theory stated above is the aforementioned study conducted by the University of Southern Denmark, which tested the validity of this hypothesis in several ways. First, the study aimed to confirm that the heavy plow was present at the time of this supposed urban and population boom dating from roughly 900 to 1300 CE. To accomplish this, they studied the age of high-backed ridges, finding that they primarily date to after 1000 CE. This confirms that the heavy plow was present during this period, especially when viewed in conjunction with the aforementioned contemporary primary source manuscript images which show the heavy plow in its complete state.[52]

Second, after establishing that the heavy plow was in use at this time, the authors of this study discussed why these high-backed ridges were found in areas where there were wet and heavy clay soils. They state, like White, that these areas were previously inaccessible to farmers since the antiquated ard did not have the ability to work through these soils, but the heavy plow did and it allowed farmers to exploit this fertile soil, which dramatically improved agricultural productivity through the advantages delineated above.[53] In turn, the study argues, this improvement led to an increased level of agricultural productivity that allowed for urbanization to occur. Interestingly, the study found that this urbanization was exclusive to these clay soil areas, which strongly suggests that the heavy plow was primarily responsible for it.[54]

The Heavy Plow and Population Growth

The Danish study makes a strong argument for the validity of Lynn White's theory that the heavy plow caused rapid urbanization in the High Middle Ages, but it does not explain if population increased with the establishment of these new towns and cities. Fortunately,

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[51] White, 78.

[52] Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 133-137.

[53] Advantages described on pages 4, 23 and 25 of this essay.

[54] White, 41-42; Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 133-138.

historians John Langdon and James Masschaele fill this gap.[55] The authors of the Danish study explain that the urbanization instigated by the heavy plow also created significant economic development in the High Middle Ages. Landgon and Masschaele argue that this period of heightened commercial activity resulted in population growth by creating new employment opportunities. New earnings gave men and women "'the green light' for family formation," which resulted in population growth.[56] The growth was exponential because as new families were created and population increased, the economy grew with them to meet the new demand. Since the economy of the High Middle Ages was primarily agrarian, it is logical that the heavy plow's exploitation of previously inaccessible rich, fertile land would have led to impressive agricultural productivity, which led to urbanization and significant economic development that allowed for men and women to have children and increase the population.[57]

Now that the heavy plow has been established as having a large impact on population growth in the High Middle Ages through its creation of urbanization and economic development, two factors still need to be covered: influences in addition to the heavy plow that helped increase population growth, and statistics that show this dramatic growth and what factors historians say are responsible for it. First, historians who study medieval population growth have stated that a warm climate, peace, and a disease-free environment were present during the High Middle Ages and helped increase population at this time. These environmental and political factors undoubtedly helped the heavy plow achieve its success. Also, other agricultural developments and technologies, such as the cultivation of protein-rich legumes, may have also contributed to population growth.[58]

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[55] Although the article is titled "Commercial Activity and Population Growth in Medieval England," the authors state on page 36 "that much of what we are saying has application for other periods, as discussed in the conclusion, and undoubtedly for many other parts of Europe, if not elsewhere, during pre-industrial times," which justifies its use here.
[56] John Langdon, and J. Masschaele. "Commercial Activity and Population Growth in Medieval England," *Past & Present* 190 (2006): 35-41.
[57] John Langdon, and J. Masschaele, "Commercial Activity and Population Growth in Medieval England," *Past & Present* 190 (2006): 35-41; James B. Tschen-Emmons, *Artifacts from Medieval Europe* (Santa Barbara: Greenwood, 2015), 16-17.
[58] David Nicholas, *Oxford Dictionary of the Middle Ages,* "Demography and Population," Oxford: Oxford University Press, 2010; John Langdon and J. Masschaele, "Commercial Activity and Population Growth in Medieval England," *Past & Present* 190 (2006): 35-41; Gimpel, "Population and Environment in the Middle Ages," *Environment and Change* 2, no. 4 (1973): 233-236; Gimpel, *Medieval Machine,* 51.

Second, although primary source statistics on medieval population are scanty, later historians have made rough estimates. Gimple states that the overall medieval population grew from twenty-seven million in the Early Middle Ages to over seventy million at the end of the High Middle Ages. Gimpel argues that this growth was due to a combination of the innovations of the agricultural revolution with emphasis on the heavy plow, a protein-rich diet, and a warm climate. Other historians have made similar arguments, such as Josiah Russell, a historian who devoted most of his career to researching medieval population growth, who argues that the massive growth experienced in the High Middle Ages in Western Europe was primarily due to technical developments in medieval agriculture, specifically the heavy plow, horse shoe, horse collar, and protein rich-crops, and a disease-free environment. Although in the minority, some historians, such as David Nicholas, argue that the population growth experienced in the High Middle Ages had little to do with advances in agricultural technology, and was primarily due to the settlement of "previously uncultivated land" pushed forward by a fair climate and fertile soil. The following analysis will show why this argument is invalid. Although new lands were brought under cultivation in northern and eastern Europe, this would not have been possible without the heavy plow.[59]

The author argues that several things support White's theory. First, it is highly possible that the heavy plow did increase population during the Early Middle Ages as White claimed, since documentary evidence shows that Germany's population increased soon after introduction of the heavy plow in the sixth century. This introduction seems to be verified by Henning's archaeological evidence as well as White's philological evidence. However, the author does agree that this was limited to Germany and possibly the Slavic East because war, bad weather, and disease prevailed in other regions at this time.[60]

Second, White's claim that the heavy plow dramatically improved population growth and led to "rapid urbanization" in the High Middle Ages is a concrete argument, especially with the secondary and primary source evidence that has confirmed and expanded his original argument.

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[59] Gimpel, *Medieval Machine,* 40-41, 51-52 and 57; David Nicholas, *Oxford Dictionary of the Middle Ages,* "Demography and Population" (Oxford: Oxford University Press, 2010); Josiah Russell, "Late Ancient and Medieval Population," *Transactions of the American Philosophical Society* 48, no. 3 (1958): 113 and 138.

[60] White, 50 and 54; David Nicholas, *Oxford Dictionary of the Middle Ages,* "Demography and Population," Oxford: Oxford University Press, 2010; Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 136.

The primary source images and text clearly show that the heavy plow was present during this period of expansion in the High Middle Ages.

Additionally, the combined scholarship of the Danish study and Langdon and Masschaele demonstrate that the heavy plow was primarily responsible for urbanization and economic development, both of which resulted in large population growth. However, the author does agree with other historians, like Gimpel and Nicolas, that the heavy plow was not the sole catalyst in this population and urban increase, but that a warm climate, peace, a disease-free environment, protein-rich legumes, and other agricultural technology like the horse collar and shoe also contributed to this growth in the High Middle Ages. The author does not agree, however, with Nicholas' argument that advances in agricultural technology had little impact on population growth but the settlement of "previously uncultivated land" of fertile soil did. This makes no sense, because these lands had not been cultivated previously since there was no heavy plow. The heavy plow was imperative for the settling and exploiting of fertile lands, so arguments that agricultural technology is irrelevant to population growth are ludicrous. These findings show that White's argument has been successfully expanded and supported, but not refuted.[61]

This discussion has paid heed to what Roland White called on later historians to do: it has expanded and improved this theory with new research instead of criticizing and writing off White's heavy plow argument as rubbish, as some past historians have done. However, there is still more work to do. The following will delineate what this work has accomplished and propose what research and studies should happen next to improve White's argument. First, when examining the historiography of his "heavy plow hypothesis," it is clear that this thesis is still valid after a half-century of scholarly review, since it is at present being tested and improved by modern historians and scientists, and nothing has replaced it. If it were found to be invalid years ago, it is unlikely that scholars would keep citing it in their studies.[62] However, the historiography has

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[61] Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 133-138 and 145; David Nicholas, *Oxford Dictionary of the Middle Ages*, "Demography and Population," Oxford: Oxford University Press, 2010; John Langdon and J. Masschaele, "Commercial Activity and Population Growth in Medieval England," *Past & Present* 190 (2006): 35-41; Gimpel, "Population and Environment in the Middle Ages," *Environment and Change* 2, no. 4 (1973): 233-236; Gimpel, *Medieval Machine*, 32-34, 38, and 51.

[62] The Danish heavy plow study by Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard notes on page 134 that White's "*heavy plow hypothesis* has also been

also shown that later scholars have expanded and improved White's theory considerably with new research, so present studies should take these insights into mind and work off them to continue testing the validity of White's thesis.[63]

Second, the discussion of the plow's origins and the evolution of its technical details supports White's argument that a heavy plow with a coulter and plowshare migrated from the Slavic east to Western Europe during the Early Middle Ages at a small scale while one with a share, coulter, and moldboard was used across Europe in the High Middle Ages with regional evolution possibly present in Britain. However, many aspects of the heavy plow's origin and technical details remain obscure and need to be researched. One, information about the heavy plow of the Early Middle Ages is scanty, and scholars should research manuscript illustrations and texts from this period to fill this gap. In addition, they should perform scientific studies like those by the University of Southern Denmark. Doing so would reveal its technical evolution at this time, show where it was used, and confirm whether White's argument for its migration from the Slavic East to Western Europe is valid. Two, scholars have thus far failed to explain why the heavy plow suddenly became popular at the turn of the eleventh century, so they should try to ascertain the reason for this. Lastly, the possible regional technical evolution of the English heavy plow in the High Middle Ages should also be researched, since it would reveal if different climatic conditions across Britain or political, economic, social developments in certain regions determined its varied evolution.[64]

Third, the discussion here also supports White's claim that the heavy plow was the primary player in the agricultural revolution of the Early and High Middle Ages while introducing factors that affected the outcome of the revolution: climate, war and peace, disease, and other agricultural innovations, such as the introduction of protein-rich crops and three-field rotation. This shows that White's argument is still valid and has been expanded and improved by later scholarship, but there is one aspect of this revolution that needs to be researched to understand its ultimate impact on this event: climate. The effects of climate on agricultural productivity in the Early and High Middle Ages need to be

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perpetuated in a leading textbook on 'Civilization in the West,' where students are told that the heavy plow 'increased population in the heavy soil areas north of the Alps.'"

[63] Alex Roland, "Once More into the Stirrups: Lynn White Jr., 'Medieval Technology and Social Change,'" *Technology and Culture* 44, No. 3 (2003): 578-583.

[64] White, 50 and 54; Gimpel, 40-41; Thomas B. Andersen, Peter S. Jensen and Christian V. Skovsgaard, "The Heavy Plough and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics* 118, January 2016: 135-137.

fleshed out to determine whether cold or warm temperatures were present in certain regions of Europe or all across. This will determine if the heavy plow had to be used in a warm climate to be successful or if it could produce the same results in a colder environment. Also, war and disease were potentially the reasons why the agricultural revolution of the early Middle Ages was small scale rather than just a cold period. In addition, it may have been limited because a warm climate only affected Germany and the Slavic East while cold prevailed elsewhere. A thorough study of climate during this period would help answer these unresolved questions.[65]

Lastly, the discussion presented White's claim that the introduction of the heavy plow was the primary reason for the population and urbanization boom in Western Europe in the High Middle Ages, which was greatly supported by later scholarship that improves and expands his original argument. However, John Langdon and James Masschaele's argument that the economic growth caused by the emergence of cities allowed for population to increase needs to be expanded to cover all of Europe instead of focusing on England exclusively. Although they state that their findings can apply to other parts of Europe generally, a thorough analysis of economic growth in European cities in heavy clay areas during this period could further support White's claim that the heavy plow was primarily responsible for the immense urban and population growth of the High Middle Ages.[66]

Ultimately, this discussion has shown that White's narrative of the heavy plow's origins and evolution and his hypothesis for the implement's major impact on early and high medieval agriculture, population, and urban growth is still valid and should be tested, expanded, and improved through new scholarship until, as reviewer Alex Roland stated in 2003, "another grand synthesis provides a more compelling view" of this topic.[67]

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[65] David Nicholas, *Oxford Dictionary of the Middle Ages,* "Demography and Population," Oxford: Oxford University Press, 2010; Gimpel, "Population and Environment in the Middle Ages," *Environment and Change* 2, no. 4 (1973): 233-236; Gimpel, *Medieval Machine,* 32-34, 38, and 51.

[66] John Langdon and J. Masschaele, "Commercial Activity and Population Growth in Medieval England," *Past & Present* 190 (2006): 35-41; White, 78.

[67] Alex Roland, "Once More into the Stirrups: Lynn White Jr., 'Medieval Technology and Social Change,'" Technology *and Culture* 44, No. 3 (2003): 585.

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